Appendix C

Anomalous Uranium and Thorium Signals in Two Passive Gamma-Ray Spectra from P2-PU-3

Appendix C

Anomalous Uranium and Thorium Signals in Two Passive Gamma-Ray Spectra from P2-PU-3

C.J. Koizumi, December 30, 2003

C-1. SITE AND DATA ACQUISITION INFORMATION

Site: INEEL Site SDA Pit 2, borehole P2-PU-3, 0.5-inch-thick steel casing

Logging System: Gamma 4B, 35 percent HPGe, serial number 36TP21095A

Logging Date: 12/10/03

Spectra:

DB441017.CHN, passive gamma ray, depth 12 feet, 300 seconds real time

DB441014.CHN, passive gamma ray, depth 13.5 feet, 300 seconds real time.

The passive gamma ray log of P2-PU-3 implies the existence of three anomalies:

- A uranium anomaly that reaches a maximum concentration of about 2,200 pCi/g at a depth of about 10.5 feet
- A thorium anomaly that reaches a maximum concentration of about 36 pCi/g at a depth of about 12 feet
- A radium anomaly that reaches a maximum concentration of about 159 pCi/g at a depth of about 14 feet.

C-1.1 Spectrum DB441017.CHN

C-1.1.1 Calculated Concentrations

The Ra-226 concentration inferred from the 1764.5-keV gamma ray spectral peak is about 34 ± 1 pCi/g. The Ra-226 concentration inferred from the 609.3-keV gamma ray spectral peak is smaller, about 19 ± 1 pCi/g.

When Ra-226 is in decay equilibrium with U-238, the Ra-226 and U-238 concentrations are equal (if expressed in decay rate per unit mass).

The U-238 concentration inferred from the Pa-234m 1001.0-keV gamma ray peak is about 70 ± 20 pCi/g.

This spectrum was recorded at a depth that was close to the maximum calculated thorium concentration.

The thorium concentration based on the Ac-228 gamma ray peaks is somewhat higher than normal background. The intensity of the 911.2-keV gamma ray peak implies a concentration of about 11 ± 1 pCi/g, and the intensity of the 969.0-keV gamma ray peak implies a concentration of about 14 ± 1 pCi/g. The concentration based on the Tl-208 2614.5-keV gamma ray peak is unusually high, around 30 ± 2 pCi/g.

C-1.1.2 Interpretations

The 1764.5- and 609.3-keV gamma rays both originate in the decay of Bi-214, so Ra-226 concentrations calculated from the spectral peak intensities should normally be nearly identical. Here, the concentration based on the 1764.5-keV gamma ray significantly exceeds the concentration based on the 609.3-keV gamma ray. The actual reason for the discrepancy is unknown, but there are several possible explanations. The spectrum was acquired at a depth where the Ra-226 [depicted as *U-238 (1764)* on log plots] concentration was not uniform. In fact, at 12 feet the Ra-226 concentration began to rise quickly as the depth increased. Since the 1764.5-keV gamma rays have more penetrating ability than the 609.3-keV gamma rays, it is likely that a greater percentage of the 1764.5-keV gamma rays from the high radium zone (between about 12 and about 15 feet) passed through the formation and reached the detector. In addition, gamma rays from the zone of elevated radium impinged on the detector at angles greater than 90 degrees relative to vertical. For such angles, the path lengths through the steel casing were greater than 0.5 inch, and any increase in path length within casing would further reduce the 609.3-keV gamma ray fluxes relative to the 1764.5-keV gamma ray fluxes. Also, this spectrum came from a depth within the processed uranium anomaly, and the processed uranium might have raised the average Z of the formation to the point that the 609.3-keV gamma ray fluxes were slightly reduced by the Z effect. All of these factors imply that the 609.3-keV gamma ray peak intensity yields an understated concentration.

The fact that the spectrum came from a depth within the zone of elevated U-238 accounts for the high uranium concentration based on the peak for the 1001.0-keV Pa-234m gamma ray.

Explanations for the thorium concentration discrepancy are more difficult to develop. The cursory investigations described next failed to reveal a reason for this discrepancy.

The idea that the intensity of the peak at 2,614.5 keV was boosted by an overlooked source was considered, but no candidate sources were found. For example, the spectrum does not have a pair of intense peaks that could be linked to two gamma rays that would cause a random sum peak at 2,614.5 keV. Also, a search of the "Gamma-Lines of the Radionuclides Ordered in Terms of Energy" section in The Gamma Rays of the Radionuclides (Erdtmann & Soyka, 1979, Verlag Chemie, Weinheim, Germany) did not reveal any credible sources other than Tl-208 for a 2614.5-keV gamma ray.

If an intense flux of gamma rays of energy 3125 keV existed, an escape peak at 2,614 keV would add to the intensity of the Th gamma ray peak, but the spectrum would not have a peak at 3,125 keV because this energy is above the range of the detector. However, the existence of 3125-keV gamma rays is considered highly unlikely, and in fact, The Gamma Rays of the Radionuclides does not list any credible sources.

The only thorium series nuclide between Ac-228 and Tl-208 with a half life long enough to be a factor in decay disequilibrium is Th-228 (half life ≈ 1.9 years). Thus, the only plausible thorium series decay disequilibrium that could account for the observed discrepancy is an excess of Th-228 relative to Th-232. Separation of Th-228 from Th-232 in the subsurface by geochemical processes is too improbable to consider, so mechanisms other than decay of Th-232 that could produce thorium series nuclides below Ac-228 were investigated. An example is alpha decay of U-232 to Th-228. None of the mechanisms

produce detectable gamma rays, so the passive gamma ray spectra do not contain information that can confirm or rule out such processes.

C-1.2 Spectrum DB441014.CHN

C-1.2.1 Calculated Concentrations

The thorium concentration inferred from the 2614.5-keV gamma ray peak intensity is about 7 pCi/g, which is somewhat higher than normal background.

Peak intensities for three gamma rays, 609.3, 1764.5, and 2204.2 keV, imply Ra-226 concentrations of 102 ± 6, 156 ± 4, and 153 ± 6 pCi/g, respectively.

The spectrum contains no hint of a peak at 1001.0 keV.

C-1.2.2 Interpretations

The intensities of the peaks for the 1764.5- and 2204.2-keV gamma rays imply a Ra-226 concentration a bit higher than 150 pCi/g. The concentration inferred from the 609.3-keV gamma ray peak is smaller, about 102 ± 5 pCi/g. The reason for this discrepancy is unknown. It should be noted that the absence of a peak for the 1001.0-keV Pa-234m gamma ray indicates that U-238 is not present in concentrations that could suppress the 609.3-keV gamma ray flux via the Z effect.

The absence of any trace of a peak at 1001.0 keV was considered unusual, and was investigated.

The 2002 SGLS calibration data acquired by logging the calibration standard SBM were retrieved because the Ra-226 concentration in SBM is 125 pCi/g, which is about the same as predicted using the 1764.5-keV gamma peak in DB441014.CHN. The U-238 concentration is also 125 pCi/g. In all of the SBM spectra, the 1001.0-keV gamma ray peak is clearly evident, and the average intensity is 2.5 c/s. The average intensity for the 1,764.5-keV gamma ray peak is 40.1 c/s. Both of these average intensities were divided by the casing corrections (to get the intensities that would have been recorded if the SBM hole had a 0.5-inch-thick casing), then the fraction of the 1,001.0-keV intensity relative to the 1764.5-keV intensity was calculated. That fraction was then used to predict the intensity of the 1,001.0-keV gamma ray peak that would be in spectrum DB441014.CHN if U-238 were present in decay equilibrium with Ra-226. The result is about 1.5 c/s.

A similar result was obtained from calculations involving a detection index. The detection index is defined as

$$\text{detection index} = \frac{(\text{gamma - ray yield}) \cdot (\text{detector efficiency})}{(\text{casing correction})} .$$

For any gamma ray, the detection index value is approximately proportional to the intensity of the associated spectral peak.

Using peak intensities from DB441014.CHN, detection indexes were calculated for the 609.3-, 1120.3-, and 1764.5-keV gamma rays. The ratios of peak intensity to detection index were 0.04, 0.05, and 0.06 for the three gamma rays. The average ratio value of 0.05 was used, along with the calculated detection index value for the 1,001.0-keV gamma ray, to estimate a peak intensity of about 1.3 c/s. This agrees with the value of 1.5 c/s estimated from SBM calibration data. The spectrum analysis program should readily find a 1.3-c/s peak (in fact, the program had no trouble locating the 1.5-c/s K-40 gamma

ray peak in DB441014.CHN), but no such peak was identified near 1001 keV. The portion of the spectrum around 1001 keV was manually magnified and inspected, and no trace of a peak was seen.

The 609.3-, 1120.3-, and 1764.5-keV gamma ray peak intensities imply that the subsurface material has a Ra-226 concentration of approximately 150 pCi/g, but the absence of a peak for the 1,001.0-keV Pa-234m gamma ray indicates that the material is deficient in U-238 in relation to the concentration corresponding to decay equilibrium with Ra-226. Some materials with these characteristics are uranium mill tailings and radium itself.

Appendix D

Stoller Long Count Reports

Appendix D

Stoller Long Count Reports

Analyses of INEEL Long Count Time Passive Gamma-Ray Spectra

Carl J. Koizumi
December 10, 2003

D-1. GENERAL REMARKS

Four high resolution passive gamma ray spectra were acquired by long stationary counting at two depth points in each of two boreholes at the Subsurface Disposal Area at the Idaho National Laboratory Radioactive Waste Management Complex. The logging vehicle was HO-68B-3573, and the gamma ray detector was a 35 percent HPGe with Serial Number 36TP21095A. The counting time was 3,000 seconds clock time for each spectrum.

The spectra were analyzed with the Canberra Aptec PCMCA/WIN spectrum analysis program, using the following settings.

- ROI Properties
  - ROI Background Line: Least square fit degree = 3, Use method 2
  - Confidence: MDA sigma = 1.645, error sigma = 2
  - Centroid Calculated: between net half max
  - Centroid Weighting: net*abs(net)*chan
  - ROI Background End Points: with 5 end channels
- Peak Search
  - Max Peak Error:120 percent
- Multifit
  - Spectrum Type: HPGe/Ge(Li)
  - Optimize Centroid Search for: Separated Overlaps
  - Peaks to be Fitted: Multiplets and Singlets
  - Whose Amplitude is ≥ Minimum Detectable Amplitude times 1.645 sigma
  - Fit with Peak Width: Fixed
  - Fit with Background: Fixed

- Accuracy
  - Maximum Iterations: 25
  - Maximum Overlaps: 8
  - Percent Change: 0.25
  - Minimum Reduced Chi Square: 0.75.

For gamma ray source identifications, a library containing only gamma rays for the natural sources was used. Thus, the only gamma rays that were identified by the analysis program were those associated with K-40, U-235 and its decay products, U-238 and its decay products, and Th-232 and its decay products. Gamma rays not identified by the analysis program were identified manually and individually.

Table D-1 shows the abbreviations used for the names of the various natural gamma ray sources.

Table D-1. Abbreviations used for natural gamma ray sources.

Abbreviation	Gamma-Ray Source	Comment
Ac/T	Ac-228	decay product of Th-232
Bi/T	Bi-212	decay product of Th-232
Bi/U	Bi-214	decay product of U-238
K/K	K-40	constituent of natural potassium
Pb/T	Pb-212	decay product of Th-232
Pb/U	Pb-214	decay product of U-238
Tl/T	Tl-208	decay product of Th-232
TlAc/T	Tl-208, Ac-228	gamma rays from the two sources have nearly equal energies
URa/U	Ra-226	decay product of U-238

D-1.1 Borehole P6-PU-1

The borehole is located in the INEEL site SDA Area 5. The names of the two spectra are DB371000.CHN and DB381000.CHN.

D-1.1.1 Spectrum DB371000.CHN

DB371000.CHN was acquired on November 24, 2003, from a depth of 15.5 feet. The dead time was 0.35 percent, and the live time was 2989.4 seconds.

Table D-2 displays the natural gamma ray source names, the spectral peak intensities, and some representative concentrations that were calculated using intensities of prominent peaks. All of the uncertainties are 2σ, corresponding to the 95 percent confidence interval.

Table D-2. Natural gamma ray sources, Spectrum DB371000.CHN

Gamma-Ray Source	ActualEnergy (keV)[a]	Measured Energy (keV)	Energy Residual (keV)	FWHM[b] (keV)	Spectral Peak Intensity (c/s)[c]	Calculated Concentration (pCi/g)
Ac/T	338.32	338.34	-0.02	1.49	0.178 ± 0.072	1.70 ± 0.69
Ac/T	794.95	794.97	-0.02	1.96	0.079 ± 0.026	—
Ac/T	911.21	911.12	0.09	2.19	0.457 ± 0.041	1.51 ± 0.14
Ac/T	968.97	968.86	0.11	2.05	0.301 ± 0.024	1.63 ± 0.13
AcBi/T	727.10	727.22	-0.12	1.76	0.094 ± 0.036	—
Bi/T	1,620.50	1,620.63	-0.13	1.68	0.021 ± 0.012	—
Bi/U	609.31	609.40	-0.09	1.76	0.607 ± 0.050	1.25 ± 0.10
Bi/U	768.36	768.31	0.05	1.51	0.060 ± 0.036	—
Bi/U	1,120.29	1,120.13	0.16	1.92	0.199 ± 0.035	—
Bi/U	1,238.11	1,237.87	0.24	1.82	0.075 ± 0.026	—
Bi/U	1,377.67	1,377.62	0.05	2.44	0.057 ± 0.022	—
Bi/U	1,407.98	1,407.88	0.10	2.29	0.046 ± 0.011	—
Bi/U	1,509.23	1,509.19	0.04	1.57	0.013 ± 0.013	—
Bi/U	1,729.60	1,729.79	-0.19	2.14	0.041 ± 0.012	—
Bi/U	1,764.49	1,764.58	-0.09	2.35	0.227 ± 0.020	1.23 ± 0.11
Bi/U	1,847.42	1,847.41	0.01	2.40	0.038 ± 0.013	—
Bi/U	2,204.21	2,203.78	0.43	2.91	0.079 ± 0.014	1.33 ± 0.23
BiPb/U	351.49	351.97	-0.48	1.76	0.374 ± 0.073	—
K/K	1,460.80	1,460.69	0.11	2.27	2.610 ± 0.062	20.67 ± 0.49
Pb/T	238.63	238.79	-0.16	1.70	0.655 ± 0.099	—
Pb/U	295.21	295.26	-0.05	1.49	0.111 ± 0.077	—
Tl/T	860.56	860.45	0.11	2.02	0.077 ± 0.031	—
Tl/T	2,614.53	2,614.49	0.04	2.89	0.663 ± 0.030	1.48 ± 0.07
TlAc/T	583.30	583.31	-0.01	1.92	0.462 ± 0.055	—
URa/U	185.91	186.01	-0.10	1.53	0.108 ± 0.084	—

a. kilo-electron-volts
b. full width at half maximum
c. counts per second

Gamma ray energy and yield values are from Firestone (Firestone, R.B., 1999, Table of Isotopes (Eighth Edition, Volume II), John Wiley & Sons, Inc., New York).

The Th-232 concentrations calculated from the intensities of the various Ac-228 gamma ray peaks and the intensity of the Tl-208 gamma ray peak are all in reasonable agreement, as are the U-238 concentrations calculated from the intensities of the various Bi-214 gamma ray peaks. The calculated potassium, uranium, and thorium concentrations are consistent with natural background at INEEL.

Data for peaks not identified by the spectrum analysis program appear in Table 3, along with proposed source identifications. The energy residuals in Table D-2 for known gamma rays are relatively small, indicating that the energies in Table D-3 are accurate.

Table D-3. Data for unidentified peaks, Spectrum DB371000.CHN.

Energy (keV)	FWHM (keV)	Peak Intensity (c/s)	Proposed Source Identification	Comments
94.02	1.58	0.107 ± 0.085	—	—
99.03	1.59	0.237 ± 0.093	Am-241	—
103.01	1.59	0.234 ± 0.097	Am-241	—
125.18	2.12	0.157 ± 0.122	Am-241	< MDA[a]
152.69	1.04	0.111 ± 0.121	FWHM too small	< MDA
510.96	2.45	0.355 ± 0.060	annihilation radiation	—
662.51	2.40	0.100 ± 0.038	Am-241	—
704.65	1.50	0.033 ± 0.037	Bi-214 ?	< MDA
741.74	2.09	0.032 ± 0.032	Bi-214 ?	< MDA
782.92	1.95	0.019 ± 0.022	Ac-228	< MDA
964.75	2.05	0.087 ± 0.017	Ac-228	—
1,224.81	1.46	0.020 ± 0.023	—	< MDA
1,280.87	1.89	0.019 ± 0.020	Bi-214	< MDA
1,400.85	2.29	0.020 ± 0.010	—	< 0MDA
1,588.09	2.39	0.059 ± 0.016	Ac-228	—
1,592.66	2.39	0.034 ± 0.014	—	—
1,631.11	0.93	0.012 ± 0.012	Ac-228	< MDA
1,692.58	1.7	0.010 ± 0.009	cal spec	< MDA
2,103.16	2.34	0.067 ± 0.016	cal spec	—
2,447.5	1.24	0.0112 ± 0.0094	Bi-214	< MDA
2,547.31	1.39	0.0037 ± 0.0036	indistinct	< MDA

a. Minimum detectable activity (calculated by the analysis program).

Some of the gamma rays in Table D-3 are likely associated with natural sources. Peaks with intensities significantly below the MDA values may actually be statistical anomalies that were erroneously identified as peaks by the spectrum analysis program. Also, the peaks with “cal spec” in the

source identification column correspond to peaks that occur in calibration spectra recorded using natural potassium, uranium, and thorium sources, so these peaks, though unidentified, are most likely linked to the naturally occurring radioelements.

Several gamma rays associated with the artificial radionuclide Am-241 were detected. Table D-4a displays details about the spectral peaks.

Table D-4a. Spectral data for Am-241 gamma rays.

Energy (keV)	Peak Intensity (c/s)	Comment	Gamma Ray Yield (γ per 100 D)	Calculated Concentration (pCi/g)
99.03	0.237 ± 0.093	—	0.0203	3,786 ± 1492
103.01	0.234 ± 0.097	—	0.0195	3,657 ± 1511
125.18	0.157 ± 0.122	< MDA	0.00408	8,784 ± 6815
662.51	0.100 ± 0.038	—	0.00036	25,197 ± 9574

Am-241 has many more gamma rays than listed in Table D-4a. Table D-4b displays the more intense Am-241 gamma rays and some quantities relevant to the detection of the gamma rays. These data will be used to explain why peaks at 123.0, 208.0, 335.4, and 722.0 keV are not observed in the spectrum.

Table D-4b. Am-241 Gamma ray data.

Energy (keV)	Gamma Ray Yield (γ per100 decays)	Detector Efficiency ((c/s) per(γ/s/g))	Inverse Casing Correction	Detection Index
99.0	0.0203	106.4	0.078	0.1687
103.0	0.0195	105.3	0.084	0.1731
123.0	0.001	101.4	0.115	0.0116
125.3	0.00408	100.5	0.118	0.0485
208.0	0.000791	100.0	0.220	0.0174
335.4	0.000496	97.3	0.318	0.0154
662.4	0.000364	89.6	0.436	0.0142
722.0	0.000196	89.3	0.450	0.0079

In Table D-4b, the gamma ray yields are expressed in gamma rays per 100 decays. The energy dependent efficiency values were calculated using the detector calibration function, and are expressed in (counts per second in a gamma ray peak) per (gamma rays per second per gram of sample); the *gamma rays per second per gram of sample* term is the gamma ray source intensity. Each *inverse casing correction* value is just the reciprocal of the casing correction for the particular energy. *Detection index* is the product of yield, efficiency, and inverse casing correction. The detection index value is related to the likelihood that a given gamma ray will produce a spectral peak.

One notes that the detection indexes for the 99.0 and 103.0-keV gamma rays are essentially equal, which is consistent with the fact that the corresponding peak intensities are nearly equal (Table D-4a). If the index for the 662.4-keV gamma ray, i.e., 0.0142, corresponds roughly to the lower limit of detection,

then the lower detection indexes for the 1,23.0 and 722.0-keV gamma rays explain why the corresponding peaks are absent.

Regarding the 208.0-keV gamma ray, there is a tiny bump in the spectrum close to this energy. This low energy region lies on an elevated part of the Compton continuum and the MDA is relatively high. If the *maximum peak error* in the *Peak Search* routine is increased from 120 percent to 130 percent, the spectrum analysis program will identify the bump as a peak at 208.6 keV with an intensity of (0.12 ± 0.14) c/s and an MDA of 0.23 c/s. Thus, the 208.0-keV gamma ray did put a minuscule signal in the spectrum, but the signal is too obscure to be identified as a peak unless the *maximum peak error* is increased. The poor quality of the peak that results from inflating the *maximum peak error* is indicated by the fact that the peak intensity is smaller than both the intensity uncertainty and the MDA.

An examination of the part of the spectrum around 335.4 keV indicates that the peak due to this Am-241 gamma ray is obscured by a peak due to the 338.3-keV gamma ray of Ac-228.

Am-241 concentrations have been calculated from the observed peak intensities and are displayed in Table D-4a. Although a concentration is shown for every Am-241 gamma ray peak, it is important to note that the calibration and casing correction functions are established down to an energy of about 180 keV, so the concentration values associated with the 99, 103, and 125-keV gamma rays are based on extrapolated calibration and casing correction functions. These values may be inaccurate, perhaps to a significant degree. Thus, the signals at 99, 103, and 125 keV are useful only to confirm the presence of Am-241. The most credible Am-241 concentration is the one based on the 662.5-keV gamma ray peak: $(25.2 \pm 9.6) \times 10^3$ pCi/g.

All of the spectra were analyzed as carefully as spectrum DB371000.CHN. However, the discussions for the other three spectra do not include details about detection index values, peak interferences, and effects of changing the spectrum analysis parameters.

D-1.1.2 Spectrum DB381000.CHN

Spectrum DB381000.CHN was acquired on December 1, 2003, from a depth of 14.5 ft. The dead time was 0.38 percent, and the live time was 2988.7 seconds.

Information about the natural gamma ray sources is displayed in Table D-5.

Table D-5. Natural gamma ray sources Spectrum DB381000.CHN

Gamma-Ray Source	Actual Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	FWHM (keV)	Spectral Peak Intensity (c/s)	Calculated Concentration (pCi/g)
Ac/T	794.95	794.93	0.02	1.65	0.046 ± 0.031	—
Ac/T	911.21	911.15	0.06	2.02	0.379 ± 0.035	1.25 ± 0.11
Ac/T	968.97	968.93	0.04	1.98	0.252 ± 0.029	1.36 ± 0.15
AcBi/T	727.10	727.31	-0.21	1.88	0.108 ± 0.027	—
Bi/T	1,620.50	1,620.79	-0.29	0.96	0.018 ± 0.013	—
Bi/U	609.31	609.43	-0.12	1.86	0.542 ± 0.052	1.12 ± 0.11
Bi/U	768.36	768.10	0.26	1.89	0.068 ± 0.017	—

Table D-5. (continued).

Gamma-Ray Source	Actual Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	FWHM (keV)	Spectral Peak Intensity (c/s)	Calculated Concentration (pCi/g)
Bi/U	934.10	933.80	0.30	1.71	0.034 ± 0.023	—
Bi/U	1,120.29	1,120.21	0.08	1.94	0.129 ± 0.028	—
Bi/U	1,238.11	1,237.97	0.14	1.72	0.077 ± 0.025	—
Bi/U	1,377.67	1,377.43	0.24	3.00	0.053 ± 0.018	—
Bi/U	1,509.23	1,508.92	0.31	2.21	0.030 ± 0.009	—
Bi/U	1,729.60	1,729.50	0.10	2.69	0.039 ± 0.013	—
Bi/U	1,764.49	1,764.57	-0.08	2.39	0.180 ± 0.019	0.98 ± 0.10
Bi/U	1,847.42	1,847.77	-0.35	2.08	0.032 ± 0.012	—
Bi/U	2,204.21	2,203.74	0.47	2.47	0.060 ± 0.014	1.01 ± 0.23
BiPb/U	351.49	352.05	-0.56	1.87	0.378 ± 0.066	—
K/K	1,460.80	1,460.71	0.09	2.26	2.136 ± 0.056	16.92 ± 0.45
Pb/T	238.63	238.93	-0.30	1.67	0.479 ± 0.050	—
Pb/U	295.21	295.53	-0.32	1.51	0.130 ± 0.065	—
Tl/T	2,614.53	2,614.49	0.04	2.71	0.570 ± 0.028	1.28 ± 0.06
TlAc/T	583.30	583.27	0.03	1.82	0.377 ± 0.046	—

Relative to spectrum DB371000.CHN, all of the concentrations are slightly lower, but all of the values are within normal ranges.

Data for peaks not identified by the spectrum analysis program appear in Table D-6.

Table D-6. Data for Unidentified peaks, Spectrum DB381000.CHN.

Energy (keV)	FWHM (keV)	Peak Intensity (c/s)	Proposed Source Identification	Comments
59.71	1.41	0.068 ± 0.077	—	< MDA
99.24	1.61	1.99 ± 0.21	Am-241	—
103.21	1.61	2.43 ± 0.21	Am-241	—
114.78	1.62	0.22 ± 0.21	—	—
125.59	1.62	1.71 ± 0.27	Am-241	—
146.78	1.53	0.30 ± 0.15	—	—
203.99	1.65	0.137 ± 0.051	Pu-239	< MDA
208.26	1.66	1.214 ± 0.064	Am-241	—
242.06	1.67	0.149 ± 0.044	—	—

Table D-6. (continued).

Energy (keV)	FWHM (keV)	Peak Intensity (c/s)	Proposed Source Identification	Comments
312.08	1.70	0.669 ± 0.070	Pa-233	(Np-237)
322.60	1.70	0.204 ± 0.056		—
332.65	1.71	0.291 ± 0.092	Pu-239	—
335.62	1.71	0.65 ± 0.11	Am-241	—
368.69	1.72	0.366 ± 0.075		—
375.61	1.73	0.400 ± 0.076	Pu-239	—
393.06	2.14	0.100 ± 0.062	Pu-239	< MDA
413.69	1.75	0.246 ± 0.069	Pu-239	—
510.90	2.39	0.374 ± 0.059	annihilation radiation	—
619.02	1.42	0.056 ± 0.032	—	—
653.32	1.84	0.043 ± 0.023	—	< MDA
662.29	1.85	0.640 ± 0.044	Am-241	—
722.05	1.87	0.226 ± 0.034	Am-241	—
755.27	1.89	0.034 ± 0.015	—	< MDA
758.48	1.89	0.032 ± 0.015	—	< MDA
964.76	1.98	0.071 ± 0.020	Ac-228	—
1,001.05	1.91	0.118 ± 0.028	Pa-234m	processed U
1,208.07	2.16	0.020 ± 0.023	Bi-214 ?	< MDA
1,401.49	2.29	0.018 ± 0.014	—	< MDA
1,501.40	2.21	0.021 ± 0.007	—	—
1,587.92	1.99	0.015 ± 0.017	Ac-228	< MDA
1,963.86	0.74	0.008 ± 0.008	FWHM too small	< MDA
1,992.76	1.27	0.006 ± 0.007	—	< MDA
2,071.47	1.00	0.006 ± 0.007	FWHM too small	< MDA
2,103.47	3.54	0.055 ± 0.014	cal spec	—
2,447.39	2.51	0.015 ± 0.010	Bi-214 ?	< MDA
2,466.43	1.04	0.004 ± 0.005	FWHM too small	< MDA
2,802.94	2.78	0.004 ± 0.004	—	—

Spectrum DB381000.CHN has peaks indicative of Am-241, Pu-239, Np-237, and processed uranium. Spectral peak data and calculated concentrations are shown in Table D-7.

Table D-7. Data for artificial gamma ray sources.

Energy (keV)	Peak Intensity (c/s)	Source	Comment	Gamma-Ray Yield (γ per 100 D)	Calculated Concentration (pCi/g)
99.24	1.99 ± 0.20	Am-241	—	0.0203	31,698 ± 3,264
103.21	2.43 ± 0.21	Am-241	—	0.0195	37,838 ± 3,312
125.59	1.71 ± 0.27	Am-241	—	0.00408	95,680 ± 15,265
208.26	1.214 ± 0.064	Am-241	—	0.00079	21,3369 ± 11,166
335.62	0.65 ± 0.11	Am-241	—	0.0005	13,9248 ± 23,093
662.29	0.640 ± 0.044	Am-241	—	0.00036	161,915 ± 11,030
722.05	0.226 ± 0.034	Am-241	—	0.0002	101,644 ± 15,091
312.08	0.669 ± 0.070	Pa-233	(Np-237)	38.6	1.92 ± 0.20
203.99	0.137 ± 0.051	Pu-239	<MDA	0.00057	33,898 ± 12,518
332.65	0.291 ± 0.092	Pu-239	—	0.00049	64,076 ± 20,341
375.61	0.400 ± 0.076	Pu-239	—	0.00155	26,683 ± 5,104
393.06	0.100 ± 0.062	Pu-239	<MDA	0.00035	29,236 ± 18,054
413.69	0.246 ± 0.069	Pu-239	—	0.00147	16,829 ± 4,703
1,001.05	0.118 ± 0.028	Pa-234m	processed U	0.837	12.3 ± 2.9

Peaks corresponding to gamma ray energies below about 180 keV should not be used for concentration calculations because such energies are below the range of the calibration function and the casing correction function. In addition, when high-Z elements (Am, Pu, U) are present in elevated concentrations, the low energy gamma rays are attenuated within the formation by the Z effect. This source self attenuation reduces the low energy gamma ray fluxes, so concentrations based on the low energy gamma ray peaks would be anomalously low.

The Am-241 concentration calculated from the 662-keV gamma ray peak intensity is $(162 \pm 11) \times 10^3$ pCi/g.

Some other features of the 662-keV gamma ray peak may be noteworthy. The peak has a normal FWHM (1.85 keV, Table D-6). The absence of peak broadening indicates that there is probably no Cs-137 gamma ray (661.6 keV) signal in the peak. Also, the calculated concentration does not significantly exceed the concentrations based on the 208 and 335-keV gamma ray peaks, so the 662-keV peak intensity is probably not inflated by a contribution from the 661.6-keV gamma ray of Cs-137. In other words, Cs-137 is likely not present.

No explanation can be offered for the apparent low Am-241 concentration based on the 722-keV gamma ray peak.

The source of the 312-keV gamma ray is identified as Pa-233, which, because of its short half life (27 days), indicates the presence of the long-lived parent, Np-237. The source identification is necessarily based on just one gamma ray. The Pa-233 gamma ray with the next highest yield has energy 300.3 keV. A peak for this gamma ray is probably absent because the yield (6.6 gammas per 100 decays) is substantially smaller than the yield for the 312.2-keV gamma ray (38.6 gammas per 100 decays).

Pu-239 is identified with confidence because of the presence of peaks associated with five Pu-239 gamma rays. Calculated concentrations fall between about 17×10^3 and 64×10^3 pCi/g. The highest value may have been inflated by peak interferences, caused, for example, by the 335-keV gamma ray of Am-241. The 375.1-keV gamma ray peak is least likely to have an interference, and the concentration inferred from the peak intensity is $(26.7 \pm 5.1) \times 10^3$ pCi/g. This value is in reasonable agreement with the concentration inferred from the 393.1-keV gamma ray peak intensity, which is another peak that is unlikely to have an interference. The reason for the low concentration based on the 413.7-keV gamma ray peak is unknown.

The 1001-keV gamma ray signal is interpreted as a Pa-234m indicator, even though a confirming peak at 766.6 keV is not observed. The absence of a peak for the 766.6-keV gamma ray is explained by the fact that the intensity of the 1001-keV gamma ray peak is quite low, but the yield for the 1001-keV gamma ray is more than two times the yield for the 766.6-keV gamma ray.

Because Pa-234m and its parent, Th-234, have short half lives (1.2 min and 24 days), the presence of U-238, the long-lived parent of Th-234, is inferred. Because of the long half life of U-238 and the short half lives of Th-234 and Pa-234m, both Th-234 and Pa-234m can be assumed to be in decay equilibrium with U-238, and (in terms of decay rate per unit mass) all three nuclides must have the same concentration, 12.3 ± 2.9 pCi/g. This concentration is substantially higher than the normal uranium background, which is represented by the concentrations based on Bi-214 in Table D-5. The fact that the U-238 concentration based on the Pa-234m gamma ray is more than 10 times higher than the natural uranium background indicates that the U-238 has been processed. In processed uranium, U-238 decay products below Ra-226 (e.g., Bi-214) are present in much smaller concentrations than would be the case if all of the nuclides in the uranium decay chain were in decay equilibrium.

D-1.2 Borehole P6-PU-2

This borehole is also located in the INEEL site SDA Area 5. Two spectra from the borehole are named DB391000.CHN and DB391001.CHN. Both spectra were recorded on December 1, 2003.

D-1.2.1 Spectrum DB391000.CHN

Spectrum DB391000.CHN was acquired from a depth of 16.0 ft. The dead time was 0.34 percent, and the live time was 2989.8 seconds.

Table D-8 displays information about the natural gamma ray sources.

Table D-8. Natural gamma ray sources, Spectrum DB391000.CHN.

Gamma-Ray Source	Actual Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	FWHM (keV)	Spectral Peak Intensity (c/s)	Calculated Concentration (pCi/g)
Ac/T	338.32	338.74	-0.42	1.90	0.069 ± 0.057	—
Ac/T	794.95	794.75	0.20	1.93	0.060 ± 0.027	—
Ac/T	911.21	910.98	0.23	1.87	0.483 ± 0.040	1.60 ± 0.13
Ac/T	968.97	968.75	0.22	1.98	0.283 ± 0.023	1.53 ± 0.13
AcBi/T	727.10	727.10	0.00	1.74	0.106 ± 0.037	—

Table D-8. (continued).

Gamma-Ray Source	Actual Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	FWHM (keV)	Spectral Peak Intensity (c/s)	Calculated Concentration (pCi/g)
Bi/T	1,620.50	1,620.55	-0.05	2.32	0.014 ± 0.008	—
Bi/U	609.31	609.42	-0.11	1.76	0.500 ± 0.045	1.03 ± 0.09
Bi/U	768.36	768.43	-0.07	1.88	0.047 ± 0.017	—
Bi/U	934.10	933.70	0.40	1.84	0.059 ± 0.029	—
Bi/U	1,120.29	1,119.96	0.33	2.17	0.210 ± 0.033	—
Bi/U	1,238.11	1,237.89	0.22	1.70	0.102 ± 0.028	—
Bi/U	1,377.67	1,377.48	0.19	2.19	0.067 ± 0.016	—
Bi/U	1,407.98	1,407.97	0.01	1.95	0.018 ± 0.016	—
Bi/U	1,729.60	1,729.93	-0.33	2.24	0.044 ± 0.013	—
Bi/U	1,764.49	1,764.90	-0.41	2.37	0.227 ± 0.020	1.23 ± 0.11
Bi/U	1,847.42	1,847.74	-0.32	2.71	0.022 ± 0.010	—
Bi/U	2,204.21	2,204.08	0.13	2.00	0.059 ± 0.014	0.99 ± 0.23
BiPb/U	351.49	352.36	-0.87	1.46	0.428 ± 0.069	—
K/K	1,460.80	1,460.76	0.04	2.18	2.678 ± 0.063	21.21 ± 0.50
Pb/T	238.63	239.54	-0.91	1.70	0.71 ± 0.12	—
Pb/U	295.21	295.88	-0.67	1.72	0.138 ± 0.076	—
Tl/T	860.56	860.44	0.12	1.86	0.041 ± 0.031	—
Tl/T	2,614.53	2,613.98	0.55	2.90	0.687 ± 0.031	1.54 ± 0.07
TlAc/T	583.30	583.29	0.01	1.82	0.491 ± 0.045	—

The concentrations are slightly higher in general than those presented in Table D-5 for spectrum DB381000.CHN, but come close to matching the concentrations in Table D-2 for spectrum DB371000.CHN.

Data for peaks not identified by the spectrum analysis program appear in Table D-9.

Table D-9. Data for unidentified peaks, Spectrum DB391000.CHN.

Energy (keV)	FWHM (keV)	Peak Intensity (c/s)	Proposed Source Identification	Comments
409.92	2.13	0.054 ± 0.055	—	< MDA
463.52	1.87	0.075 ± 0.054	Sb-125 ?	< MDA
510.96	2.36	0.379 ± 0.062	annihilation radiation	—
772.46	1.88	0.042 ± 0.016	—	< MDA

Table D-9. (continued).

Energy (keV)	FWHM (keV)	Peak Intensity (c/s)	Proposed Source Identification	Comments
785.79	2.79	0.039 ± 0.033	—	< MDA
805.85	—	0.024 ± 0.025	—	< MDA
950.98	0.9	0.027 ± 0.027	—	< MDA
964.55	1.98	0.098 ± 0.017	Eu-152 ?	—
1,152.89	1.34	0.027 ± 0.025	—	< MDA
1,282.18	2.15	0.021 ± 0.014	—	< MDA
1,373.12	2.19	0.014 ± 0.012	—	< MDA
1,543.12	1.05	0.010 ± 0.011	—	< MDA
1,564.23	0.84	0.010 ± 0.010	—	< MDA
1,582.41	2.3	0.014 ± 0.007	—	< MDA
1,588.3	2.3	0.064 ± 0.011	Ac-228	—
1,592.91	2.31	0.045 ± 0.010	Tl-208 ?	—
1,630.83	2.33	0.024 ± 0.008	Ac-228	—
1,661.33	1.44	0.010 ± 0.010	—	< MDA
1,683.54	1.59	0.019 ± 0.011	—	—
2,104.02	2.9	0.076 ± 0.014	—	—
2,118.27	1.58	0.016 ± 0.010	—	—
2,152.67	1.01	0.011 ± 0.008	—	< MDA
2,446.91	2.11	0.013 ± 0.009	Bi-214	< MDA
2,554.47	1.99	0.003 ± 0.003	—	< MDA

Spectrum DB391000.CHN has only two peaks for gamma rays that could be associated with artificial radionuclides: 463.5 keV (Sb-125) and 964.5 (Eu-152). However, these artificial sources are probably not present.

The most intense Sb-125 gamma ray has energy 427.9 keV and yield 29.6 gammas per 100 decays. The next most intense gamma ray has energy 600.6 keV and yield 17.9 gammas per 100 decays. The 463.4-keV gamma ray of Sb-125 is the fourth most intense, with a yield of 10.5 gammas per 100 decays. Since the 427.9-keV gamma ray has a yield about 3 times higher than the yield of the 463.4-keV gamma ray, but no peak corresponding to the 427.9-keV gamma ray is evident, Sb-125 must not be present. The 463-keV peak may be associated with the Ac-228 gamma ray of energy 463.0 keV, or the peak may be spurious (the intensity is below the MDA).

Similarly, the 964.1-keV gamma ray of Eu-152 is the second most intense, with a yield of 14.4 gammas per 100 decays. The most intense Eu-152 gamma ray has energy 1408.0 keV and yield 20.8 gammas per 100 decays. There is no peak corresponding to 1408 keV; therefore, Eu-152 must be absent. The 964-keV peak may be associated with the Ac-228 gamma ray of energy 964.8 keV.

Spectrum DB391000.CHN apparently contains no signals due to artificial radionuclides.

D-1.2.2 Spectrum DB391001.CHN

Spectrum DB391001.CHN was acquired from a depth of 15.0 ft. The dead time was 0.54 percent, and the live time was 2,983.7 seconds.

Table D-10 displays information about the natural gamma ray sources.

Table D-10. Natural Gamma-Ray Sources, Spectrum DB391001.CHN.

Gamma-Ray Source	Actual Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	FWHM (keV)	Spectral Peak Intensity (c/s)	Calculated Concentration (pCi/g)
Ac/T	794.95	794.74	0.21	1.93	0.060 ± 0.017	—
Ac/T	911.21	910.98	0.23	1.99	0.358 ± 0.033	1.18 ± 0.11
Ac/T	968.97	968.74	0.23	2.02	0.233 ± 0.023	1.26 ± 0.12
AcBi/T	727.10	727.51	-0.41	1.89	0.096 ± 0.020	—
Bi/U	609.31	609.40	-0.09	1.83	0.529 ± 0.034	1.09 ± 0.07
Bi/U	768.36	767.89	0.47	1.91	0.068 ± 0.024	—
Bi/U	934.10	934.01	0.09	2.00	0.056 ± 0.014	—
Bi/U	1,120.29	1,120.07	0.22	2.10	0.191 ± 0.014	—
Bi/U	1,238.11	1,237.53	0.58	2.16	0.076 ± 0.031	—
Bi/U	1,377.67	1,377.57	0.10	2.23	0.050 ± 0.017	—
Bi/U	1,509.23	1,509.34	-0.11	2.30	0.026 ± 0.010	—
Bi/U	1,729.60	1,730.16	-0.56	2.41	0.036 ± 0.013	—
Bi/U	1,764.49	1,764.89	-0.40	2.43	0.189 ± 0.024	1.03 ± 0.13
Bi/U	1,847.42	1,847.96	-0.54	2.47	0.022 ± 0.015	—
Bi/U	2,204.21	2,204.13	0.08	2.65	0.063 ± 0.012	1.05 ± 0.20
BiPb/U	351.49	352.48	-0.99	1.70	0.427 ± 0.073	—
K/K	1,460.80	1,460.80	0.00	2.27	2.086 ± 0.086	16.52 ± 0.68
Pb/T	238.63	239.54	-0.91	1.64	0.395 ± 0.086	—
Tl/T	860.56	860.60	-0.04	1.96	0.083 ± 0.024	—
Tl/T	2,614.53	2,614.07	0.46	2.86	0.694 ± 0.031	1.55 ± 0.07
TlAc/T	583.30	583.39	-0.09	1.82	0.389 ± 0.032	—

The concentrations of the natural gamma ray sources agree with the concentrations inferred from spectrum DB381000.CHN (Table D-5). In general, these concentrations are slightly lower than the concentrations deduced from spectra DB371000.CHN (Table D-2) and DB391000.CHN (Table D-8).

Table D-11 displays data for peaks not identified by the spectrum analysis program.

Table D-11. Data for unidentified peaks, Spectrum DB391001.CHN.

Energy (keV)	FWHM (keV)	Peak Intensity (c/s)	Proposed Source Identification	Comments
61.33	1.55	0.072 ± 0.054	—	< MDA
204.73	1.63	0.151 ± 0.061		< MDA
208.98	1.63	0.334 ± 0.062	Am-241	—
312.44	1.68	0.193 ± 0.044	—	—
333.23	1.69	0.207 ± 0.073	Pu-239	—
345.42	1.70	0.236 ± 0.070	—	—
375.54	1.71	0.630 ± 0.075	Pu-239	—
382.86	1.72	0.079 ± 0.055	—	< MDA
393.31	1.72	0.236 ± 0.035	Pu-239	—
409.99	1.73	0.065 ± 0.029	—	< MDA
414.00	1.73	0.696 ± 0.042	Pu-239	—
451.76	1.75	0.098 ± 0.019	—	—
463.61	1.76	0.062 ± 0.026	—	< MDA
511.02	2.70	0.556 ± 0.071	annihilation radiation	—
662.47	1.86	0.237 ± 0.026	Am-241	—
721.95	1.89	0.134 ± 0.022	Am-241	—
964.44	2.02	0.060 ± 0.017	—	—
1,000.88	2.03	0.079 ± 0.022	Pa-234m	—
1,588.3	2.34	0.024 ± 0.011	—	< MDA
1,592.87	2.34	0.031 ± 0.011	—	—
1,630.89	2.36	0.023 ± 0.009	—	—
1,661.73	2.37	0.013 ± 0.008	—	< MDA
1,712.56	2.40	0.012 ± 0.007	—	< MDA
2,103.77	2.60	0.080 ± 0.012	—	—
2,223.34	2.66	0.086 ± 0.013	H capture	—
2,447.32	2.78	0.022 ± 0.007	Bi-214	—
2,751.52	2.93	0.003 ± 0.024	—	< MDA

Spectrum DB391001.CHN has peaks corresponding to gamma rays from Am-241 and Pu-239. The 1001-keV signal is assigned to Pa-234m, though a confirming peak for the 766.6-keV gamma ray is not observed.

Table D-12 shows the calculated Am-241, Pu-239, and Pa-234m concentrations.

Table D-12. Data for artificial gamma ray sources.

Energy (keV)	Peak Intensity (c/s)	Source	Comment	Gamma-Ray Yield (γ per 100 D)	Calculated Concentration (pCi/g)
208.98	0.334 ± 0.062	Am-241	—	0.00079	5,8594 ± 1,0923
662.47	0.237 ± 0.026	Am-241	—	0.00036	5,9944 ± 6,569
721.95	0.134 ± 0.022	Am-241	—	0.0002	6,0528 ± 9,804
333.23	0.207 ± 0.073	Pu-239	—	0.00049	4,5693 ± 1,6062
375.54	0.630 ± 0.075	Pu-239	—	0.00155	4,2077 ± 4,987
393.31	0.236 ± 0.035	Pu-239	—	0.00035	6,8747 ± 1,0142
414.00	0.696 ± 0.042	Pu-239	—	0.00147	4,7538 ± 2,868
1,000.88	0.079 ± 0.022	Pa-234m	processed U	0.837	8.2 ± 2.3

None of the peak intensities in Table D-12 fall below MDA values. The Am-241 concentration calculated from the 662-keV gamma ray peak intensity is $(59.9 \pm 6.6) \times 10^3$ pCi/g; concentrations calculated from other gamma ray data are in reasonable agreement with this.

For Pu-239, the 375.5-keV gamma ray peak is least likely to have interferences; the calculated concentration is $(42.1 \pm 5.0) \times 10^3$ pCi/g. This concentration agrees with concentrations calculated from the 333 and 414-keV gamma ray data. For unknown reasons, the concentration inferred from the 393-keV gamma ray peak is higher than the other concentrations.

The peak at 1,000.9 keV suggests Pa-234m, with a concentration of 8.2 ± 2.3 pCi/g. The discussion of Pa-234m in relation to spectrum DB381000.CHN applies here; thus, processed uranium is present, with a U-238 concentration of about 8.2 ± 2.3 pCi/g.

Spectrum DB391001.CHN has a peak that is apparently due to the 2223.3-keV hydrogen neutron capture gamma ray. The concentrations of alpha emitters must be so high that alpha-neutron reactions with oxygen yield neutrons in numbers sufficient to produce detectable gamma ray fluxes when captured by hydrogen (in water).

The spectrum was examined for gamma ray peaks associated with capture gamma rays from tungsten, germanium, aluminum, iron, chlorine, silicon, and calcium, but no eligible peaks were found. The intensity of the 351-keV “uranium” gamma ray peak (Table D-10) is comparable to the peak intensities for the same gamma ray in the other spectra, indicating that there is no interference from the 352.2-keV neutron capture gamma ray of iron.

Passive Gamma-Ray Spectra from INEEL Boreholes P6-PU-1 and P6-PU-2

February 11, 2004

D-2. Analysis Method

Five passive gamma ray spectra from each borehole were analyzed, using the method described in the attachment "INEEL Passive Gamma-Ray Spectrum DB501000.CHN." This paper presents the results of the analyses.

Each spectrum was energy-calibrated, then analyzed with a spectrum analysis program by two methods. The important analysis settings common to both methods were as follows.

- ROI Properties
  - Background curve: third degree
  - Background end points: five on each side of the peak
- Peaksearch
  - Maximum error of 100 percent.

The first method utilized the *peaksearch* and *identify* algorithms in the analysis program. The second method utilized the *peaksearch*, *multifit*, and *identify* algorithms. *Peaksearch* finds all of the features in a spectrum that meet the analysis criteria for a peak. *Multifit* fits Gaussian functions to peaks and discards peaks with parameters, such as full widths at half maxima (FWHM), that do not meet resolution and other criteria. For the second method, the spectra were individually resolution-calibrated. The two methods were used because of the extraordinarily long (8-hour) count times. Gain shift could have caused spectral peak broadening, and the analysis program could have resolved broad peaks into "multiplets," or superimposed peaks. By comparing results of the two analyses, false multiplets could be identified.

The *Identify* algorithm in the analysis program utilized a source identification data base (library) containing the most intense gamma rays for Am-241, Co-60, Cs-134, Cs-137, Eu-152, Eu-154, Np-237, Pu-239, Ru-106, Sb-125, Sb-126, and Tc-99. Nuclides and gamma rays in this library are displayed in Table D-13.

Table D-13. Source Data.

Source Nuclide	Energy (keV)
Am-241	103.0
Am-241	125.3
Co-60	1,173.2
Co-60	1,332.5
Cs-134	795.8
Cs-137	661.6

Table D-13. (continued).

Source Nuclide	Energy (keV)
Eu-152	121.8
Eu-152	1,408.0
Eu-154	1,004.7
Eu-154	1,274.4
Eu-155	105.3
K-40	1,460.8
Np-237	312.2
Np-237	300.3
Pu-239	129.3
Pu-239	375.1
Ru-106	621.9
Sb-125	176.3
Sb-125	463.4
Sb-125	600.6
Sb-126	695.0
Tc-99	89.5
Th-232	583.2
Th-232	911.2
Th-232	2,614.5
U-235	185.7
U-235	163.3
U-238	351.9
U-238	609.3
U-238	1,764.5
U-238p	766.4
U-238p	1,001.0

The analysis program identified any man-made sources in Table D-13 that had concentrations high enough to produce detectable gamma ray peaks.

Only a few of the gamma rays due to the natural sources (potassium, uranium, and thorium) appear in Table D-13. Many of the gamma rays from natural sources were not included because a number of the energies nearly coincide with energies of gamma rays from the man-made sources. Thus, for example, the 1408.0-keV gamma ray of Bi-214 (uranium series) was left out to prevent the analysis program from making a Bi-214 identification then letting the 1408.0-keV gamma ray of Eu-152 go undetected.

D-2.1 Analysis Results for Borehole P6-PU-1

Five spectra were acquired from this borehole. The names of the spectra and the associated depths are as follows.

Spectrum Name	Depth
DB551000	19.92 ft
DB561000	16.0 ft
DB571000	15.5 ft
DB581000	15.0 ft
DB591000	14.5 ft

D-2.1.1 Spectrum DB551000

Almost all of the peaks are correlated to gamma rays from the natural sources. The analysis program associated the peak at 794.6 keV with Cs-134, but the energy residual was large and the peak is more likely due to the 794.9-keV gamma ray of Ac-228. Likewise, the analysis program associated the peak at 1408.0 keV with Eu-152, but since peaks due to Eu-152 gamma rays at 121.8 keV and 964.1 keV were absent, the peak is probably due to the 1408.0-keV gamma ray of Bi-214.

The source for the 1537.9-keV gamma ray is unidentified. The peak is not classified as spurious because peaks corresponding to nearly the same energy were also observed in spectra DB561000, DB571000, and DB581000.

No peaks were unambiguously associated with gamma rays from man-made sources.

Table D-14. Data for Spectrum DB551000.

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA[a] (c/s)	Analyst Comments
		39.38		0.660	0.364	0.018	probably a spurious low energy peak
		40.50		1.661	0.021	0.023	probably a spurious low energy peak
		44.63		1.053	0.021	0.028	probably a spurious low energy peak
		46.12		0.353	0.377	0.033	probably a spurious low energy peak
		51.62		0.337	0.023	0.036	probably not Pu-239 at 51.6 keV; no confirming gammas
		158.73		0.039	0.030	0.049	below MDA, probably spurious
U235	185.72	186.60	-0.88	0.057	0.014	0.047	Ra-226 (U series), 186.1 keV; U-235, 185.7 keV
		209.50		0.036	0.013	0.044	below MDA, probably spurious
		239.10		0.502	0.072	0.042	Pb-212 (Th series), 238.6 keV
		270.57		0.042	0.011	0.035	Ac-228 (Th series), 270.2 keV

Table D-14. (continued).

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA[a] (c/s)	Analyst Comments
		277.76		0.027	0.010	0.034	Tl-208 (Th series), 277.4 keV
		295.51		0.167	0.036	0.035	Pb-212 (Th series), 295.2 keV
		328.34		0.033	0.009	0.031	Ac-228 (Th series), 328.0 keV; Bi-212 (Th series), 328.0 keV
		338.52		0.155	0.010	0.030	Ac-228 (Th series), 338.3 keV
U238	351.92	352.09	-0.17	0.420	0.016	0.031	Pb-214 (U series), 351.9 keV
		389.03		0.020	0.008	0.025	below MDA, probably spurious
		403.35		0.012	0.007	0.024	below MDA, probably spurious
		409.38		0.025	0.007	0.025	Ac-228 (Th series), 409.5 keV
		462.86		0.055	0.009	0.023	Ac-228 (Th series), 463.0 keV
		510.70		0.306	0.025	0.026	annihilation radiation, 511.0 keV
		572.00		0.019	0.010	0.019	near MDA, probably spurious
Th232	583.19	583.07	0.12	0.447	0.017	0.021	Tl-208 (Th series), 583.2 keV
U238	609.31	609.15	0.16	0.573	0.015	0.020	Bi-214 (U series), 609.3 keV
		665.12		0.023	0.005	0.017	Bi-214 (U series) 665.4 keV
		727.01		0.105	0.009	0.017	Bi-212 (Th series), 727.3 keV
		755.10		0.011	0.006	0.015	Ac-228 (Th series), 755.3 keV
U238p	766.36	768.05	-1.69	0.056	0.013	0.016	Bi-214 (U series) 768.3 keV
		772.20		0.015	0.008	0.013	Ac-228 (Th series), 772.3 keV
		785.38		0.016	0.010	0.015	Pb-214 (U series), 785.9 keV; Bi-212 (Th series) 785.4 keV
Cs134	795.85	794.62	1.23	0.062	0.011	0.015	Ac-228 (Th series), 794.9 keV
		835.59		0.018	0.007	0.014	Ac-228 (Th series), 835.7 keV
		839.43		0.017	0.007	0.013	Ac-228 (Th series), 840.4 keV
		860.23		0.068	0.005	0.015	Tl-208 (Th series), 860.6 keV
		904.37		0.012	0.005	0.013	Ac-228 (Th series), 904.2 keV
Th232	911.21	910.87	0.34	0.419	0.011	0.014	Ac-228 (Th series), 911.2 keV
		933.69		0.043	0.005	0.014	Bi-214 (U series), 934.1 keV
		949.63		0.017	0.006	0.013	K-40 gamma escape peak (949.8 keV)
		964.36		0.083	0.007	0.013	Bi-214 (U series) 964.1 keV

Table D-14. (continued).

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA[a] (c/s)	Analyst Comments
		968.58		0.256	0.010	0.013	Ac-228 (Th series), 969.0 keV
U238p	1,001.03	1,000.92	0.11	0.015	0.004	0.012	Pa-234m (U series), 1001.0 keV
		1,078.50		0.009	0.005	0.011	Bi-212 (Th series), 1078.6 keV
		1,119.89		0.199	0.007	0.013	Bi-214 (U series), 1120.3 keV
		1,154.93		0.021	0.004	0.012	Bi-214 (U series), 1155.2 keV
		1,237.92		0.082	0.006	0.013	Bi-214 (U series), 1238.1 keV
		1,280.91		0.019	0.004	0.011	Bi-214 (U series), 1281.0 keV
		1,326.47		0.004	0.003	0.008	below MDA, probably spurious
		1,377.52		0.054	0.005	0.009	Bi-214 (U series), 1377.7 keV
		1,385.28		0.012	0.004	0.008	Bi-214 (U series), 1385.3 keV
		1,401.53		0.011	0.003	0.009	Bi-214 (U series), 1401.5 keV
Eu152	1,408.01	1,408.00	0.01	0.032	0.003	0.009	Bi-214 (U series), 1408.0 keV no confirming Eu-152 gamma)
K-40	1,460.83	1,460.83	0.00	2.111	0.057	0.009	K-40, 1460.8 keV
		1,495.87		0.014	0.003	0.006	Ac-228 (Th series), 1495.9 keV
		1,509.36		0.027	0.004	0.007	Bi-214 (U series), 1509.2 keV
		1,537.86		0.021	0.192	0.004	Unknown. Also observed in DB561000, DB571000, DB581000, DB531000
		1,557.17		0.005	0.002	0.006	Ac-228 (Th series), 1557.1 keV
		1,581.86		0.013	0.004	0.005	Ac-228 (Th series), 1580.5 keV
		1,588.38		0.050	0.006	0.006	Ac-228 (Th series), 1588.2 keV
		1,592.88		0.036	0.005	0.006	2614.5 keV (Tl-208) double escape peak at 1592.5 keV
		1,599.21		0.003	0.003	0.005	below MDA; Bi-214 (U series), 1599.3 keV
		1,620.94		0.022	0.004	0.006	Bi-212 (Th series), 1620.5 keV
		1,630.99		0.026	0.003	0.006	Ac-228 (Th series), 1630.6 keV
		1,638.75		0.011	0.002	0.005	Ac-228 (Th series), 1638.3 keV
		1,661.67		0.014	0.002	0.006	Bi-214 (U series), 1661.3 keV
		1,693.23		0.004	0.002	0.005	below MDA, probably spurious

Table D-14. (continued).

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA[a] (c/s)	Analyst Comments
		1,708.76		0.003	0.002	0.005	below MDA, probably spurious
		1,730.12		0.038	0.004	0.005	Bi-214 (U series), 1729.6 keV
U238	1,764.49	1,765.02	-0.53	0.220	0.010	0.006	Bi-214 (U series), 1764.5 keV
		1,838.87		0.003	0.002	0.005	Bi-214 (U series), 1838.4 keV
		1,848.20		0.027	0.003	0.005	Bi-214 (U series), 1847.4 keV
		2,103.78		0.061	0.007	0.005	2614.5 keV (Tl-208) escape peak at 2103.5 keV
		2,118.99		0.013	0.002	0.005	Bi-214 (U series), 2118.5 keV
		2,204.38		0.069	0.005	0.005	Bi-214 (U series), 2204.2 keV
		2,294.13		0.004	0.002	0.005	Bi-214 (U series), 2293.4 keV
		2,347.18		0.003	0.002	0.005	below MDA, probably spurious
		2,447.58		0.022	0.002	0.004	Bi-214 (U series), 2447.9 keV
Th232	2,614.53	2,614.34	0.19	0.541	0.029	0.002	Tl-208 (Th series), 2614.5 keV

a. MDA = minimu detectable activity.

D-2.1.2 Spectrum DB561000

Most of the peaks are associated with gamma rays from the natural background. The 794.6-keV and 1408.0-keV gamma rays probably originate in natural background and not Cs-134 or Eu-152.

There are low intensity peaks corresponding to 99.7, 103.6, and 126.0 keV, which apparently indicate Am-241, and a feeble peak (intensity below the MDA) corresponding to 376.0 keV may be indicative of Pu-239. The case for Pu-239 is quite weak; the case for Am-241 is slightly stronger.

There is a peak due to a 1454.5-keV gamma ray of unknown origin. In DB561000 the intensity of the 1454.5-keV peak is below the MDA, but the peak is not classified as spurious because a peak corresponding to 1454.3 keV exists in spectrum DB591000.

Table D-15. Data for Spectrum DB561000

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
		99.68		0.065	0.016	0.044	Am-241 (99.0 keV)
Am241	103.00	103.63	-0.63	0.067	0.017	0.048	Am-241 (103.0 keV)
Am241	125.30	126.03	-0.73	0.077	0.028	0.053	Am-241 (125.3 keV)
		131.31		0.046	0.028	0.050	below MDA, probably spurious
U235	185.72	186.22	-0.50	0.066	0.021	0.050	Ra-226 (U series), 186.1 keV;

Table D-15. (continued).

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
							U-235, 185.7 keV
		208.85		0.061	0.014	0.047	Ac-228 (Th series), 209.2 keV; Am-241, 208.0 keV
		238.97		0.525	0.041	0.045	Pb-212 (Th series), 238.6 keV
		270.62		0.046	0.011	0.038	Ac-228 (Th series), 270.2 keV
		295.39		0.186	0.023	0.037	Pb-212 (Th series), 295.2 keV
		338.38		0.142	0.022	0.033	Ac-228 (Th series), 338.3 keV
U238	351.92	351.96	-0.04	0.393	0.018	0.031	Pb-214 (U series), 351.9 keV
		375.96		0.017	0.008	0.026	below MDA, may be spurious or may be Pu-239 at 375.1 keV
		462.83		0.068	0.008	0.024	Ac-228 (Th series), 463.0 keV
		510.65		0.317	0.030	0.027	annihilation radiation, 511.0 keV
Th232	583.19	582.97	0.22	0.488	0.020	0.021	Tl-208 (Th series), 583.2 keV
U238	609.31	609.09	0.22	0.550	0.022	0.020	Bi-214 (U series), 609.3 keV
		727.03		0.108	0.011	0.018	Bi-212 (Th series), 727.3 keV
		754.76		0.013	0.005	0.015	Ac-228 (Th series), 755.3 keV
		763.25		0.016	0.009	0.016	below MDA, may be Tl-208 (Th series), 763.1 keV
		768.00		0.063	0.010	0.017	Bi-214 (U series) 768.3 keV
		772.06		0.028	0.010	0.016	Ac-228 (Th series), 772.3 keV
		785.30		0.030	0.009	0.016	Pb-214 (U series), 785.9 keV; Bi-212 (Th series) 785.4 keV
Cs134	795.85	794.64	1.21	0.074	0.010	0.016	Ac-228 (Th series), 794.9 keV
		829.93		0.013	0.005	0.015	Ac-228 (Th series), 830.5 keV
		835.31		0.037	0.005	0.015	Ac-228 (Th series), 835.7 keV
		839.87		0.022	0.005	0.015	Ac-228 (Th series), 840.4 keV
		860.26		0.078	0.008	0.016	Tl-208 (Th series), 860.6 keV
		870.33		0.010	0.006	0.014	below MDA, probably spurious
		873.63		0.011	0.008	0.013	below MDA, probably spurious
		903.46		0.014	0.011	0.017	below MDA,

Table D-15. (continued).

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
							may be Ac-228 (Th series), 904.2 keV
Th232	911.21	910.84	0.37	0.454	0.022	0.016	Ac-228 (Th series), 911.2 keV
		933.71		0.035	0.009	0.014	Bi-214 (U series), 934.1 keV
		964.39		0.088	0.012	0.015	Bi-214 (U series) 964.1 keV
		968.58		0.289	0.016	0.015	Ac-228 (Th series), 969.0 keV
		1094.43		0.010	0.003	0.012	below MDA, probably spurious
		1119.98		0.207	0.006	0.014	Bi-214 (U series), 1120.3 keV
		1154.97		0.021	0.004	0.013	Bi-214 (U series), 1155.2 keV
		1237.96		0.079	0.008	0.014	Bi-214 (U series), 1238.1 keV
		1377.52		0.059	0.004	0.010	Bi-214 (U series), 1377.7 keV
		1385.17		0.015	0.003	0.009	Bi-214 (U series), 1385.3 keV
		1401.61		0.013	0.003	0.009	Bi-214 (U series), 1401.5 keV
Eu152	1,408.01	1408.02	-0.01	0.033	0.004	0.009	Bi-214 (U series), 1408.0 keV (Eu-152 ruled out, no 121.8 keV peak)
		1454.45		0.005	0.004	0.007	below MDA, but observed in DB591000
K-40	1,460.83	1460.84	-0.01	2.557	0.073	0.009	K-40, 1460.8 keV
		1495.97		0.016	0.003	0.007	Ac-228 (Th series), 1495.9 keV
		1501.63		0.010	0.003	0.007	Ac-228 (Th series), 1501.6 keV
		1509.33		0.026	0.004	0.007	Bi-214 (U series), 1509.2 keV
		1527.84		0.006	0.005	0.006	may be spurious
		1529.02		0.010	0.004	0.006	may be spurious
		1530.48		0.005	0.005	0.006	below MDA, probably spurious
		1538.72		0.004	0.004	0.006	below MDA, may be B-214 (U series), 1538.5 keV
		1581.90		0.015	0.005	0.006	Ac-228 (Th series), 1580.5 keV
		1588.40		0.055	0.008	0.007	Ac-228 (Th series), 1588.2 keV
		1592.86		0.037	0.007	0.007	2614.5 keV (Tl-208) double escape peak at 1592.5 keV
		1620.91		0.021	0.004	0.007	Bi-212 (Th series), 1620.5 keV
		1630.83		0.030	0.005	0.006	Ac-228 (Th series), 1630.6 keV

Table D-15. (continued).

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
		1661.59		0.009	0.003	0.006	Bi-214 (U series), 1661.3 keV
		1701.85		0.003	0.002	0.005	below MDA, probably spurious
		1730.09		0.036	0.004	0.006	Bi-214 (U series), 1729.6 keV
U238	1,764.49	1765.02	-0.53	0.215	0.011	0.006	Bi-214 (U series), 1764.5 keV
		2103.84		0.076	0.006	0.006	2614.5 keV (Tl-208) escape peak at 2103.5 keV
		2118.98		0.015	0.003	0.005	Bi-214 (U series), 2118.5 keV
		2204.33		0.065	0.004	0.006	Bi-214 (U series), 2204.2 keV
		2293.05		0.004	0.002	0.005	Bi-214 (U series), 2293.4 keV
		2404.05		0.003	0.001	0.004	below MDA, probably spurious
		2405.15		0.003	0.003	0.004	below MDA, probably spurious
		2447.58		0.021	0.003	0.005	Bi-214 (U series), 2447.9 keV
		2562.47		0.002	0.001	0.002	below MDA, probably spurious
		2564.95		0.003	0.001	0.002	may be spurious
		2566.43		0.002	0.001	0.002	may be spurious
Th232	2,614.53	2614.33	0.20	0.635	0.025	0.003	Tl-208 (Th series), 2614.5 keV

D-2.1.3 Spectrum DB571000

As before, gamma rays the analysis program associated with Cs-134 and Eu-152 are actually due to the natural background. Gamma ray peaks corresponding to 103.6, 125.9, 208.6, and 721.8 keV indicate the presence of Am-241, and a peak corresponding to 312.1 keV suggests the presence of Np-237. (The gamma ray originates in Pa-233, which is a short-lived decay product of Np-237.) Spectrum DB571000 does not show a confirming Np-237 peak at 300.3 keV, but spectrum DB581000 has a 312.2-keV peak and a confirming peak at 300.5 keV. Low intensity peaks corresponding to 375.3 and 413.6 keV indicate the presence of Pu-239 at a concentration barely above the detection limit.

Table D-16. Data for Spectrum DB571000

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
		38.74		0.653	0.226	0.024	probably a spurious low energy peak
		40.78		1.356	0.024	0.033	probably a spurious low energy peak
		41.26		0.500	0.234	0.030	probably a spurious low energy peak
		43.83		0.338	0.236	0.037	probably a spurious low energy peak
		47.52		0.418	0.025	0.039	Am-241, Pu-239 (?)

Table D-16. (continued).

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
		99.68		0.177	0.026	0.048	Am-241 (99.0 keV)
Am241	103.00	103.60	-0.60	0.192	0.027	0.052	Am-241 (103.0 keV)
Am241	125.30	125.90	-0.60	0.155	0.035	0.057	Am-241 (125.3 keV)
U235	185.72	186.35	-0.63	0.091	0.015	0.054	Ra-226 (U series), 186.1 keV; U-235, 185.7 keV
		208.60		0.118	0.021	0.051	Am-241 (208.0 keV)
		238.97		0.567	0.060	0.048	Pb-212 (Th series), 238.6 keV
		270.61		0.037	0.011	0.038	Ac-228 (Th series), 270.2 keV
		295.37		0.200	0.029	0.039	Pb-212 (Th series), 295.2 keV
Np237	312.17	312.10	0.07	0.049	0.015	0.035	NP-237. No confirming lines here, but DB581000 has a confirming line
		338.51		0.119	0.029	0.034	Ac-228 (Th series), 338.3 keV
U238	351.92	351.93	-0.01	0.414	0.022	0.031	Pb-214 (U series), 351.9 keV
		368.77		0.024	0.009	0.028	Pu-239 (367.1 keV, 368.6 keV)
		375.39		0.028	0.009	0.030	Pu-239 (375.1 keV)
		409.49		0.021	0.008	0.026	Ac-228 (Th series), 409.5 keV
		413.65		0.030	0.008	0.027	Pu-239 (413.7 keV)
		462.88		0.068	0.011	0.024	Ac-228 (Th series), 463.0 keV
		510.62		0.352	0.026	0.027	annihilation radiation, 511.0 keV
		562.43		0.019	0.010	0.020	Ac-228 (Th series), 562.5 keV
Th232	583.19	582.97	0.22	0.487	0.019	0.021	Tl-208 (Th series), 583.2 keV
U238	609.31	609.08	0.23	0.550	0.029	0.020	Bi-214 (U series), 609.3 keV
Cs137	661.66	661.87	-0.21	0.067	0.015	0.019	probably Am-241 at 662.4 keV
		721.84		0.030	0.008	0.016	Am-241 (722.0 keV)
		726.93		0.120	0.009	0.017	Bi-212 (Th series), 727.3 keV
U238p	766.36	767.95	-1.59	0.054	0.013	0.016	Bi-214 (U series) 768.3 keV
		772.20		0.011	0.010	0.016	Ac-228 (Th series), 772.3 keV
		785.28		0.032	0.007	0.015	Pb-214 (U series), 785.9 keV Bi-212 (Th series) 785.4 keV
Cs134	795.85	794.59	1.26	0.071	0.007	0.016	Ac-228 (Th series), 794.9 keV
		829.96		0.012	0.006	0.015	Ac-228 (Th series), 830.5 keV
		835.45		0.029	0.006	0.015	Ac-228 (Th series), 835.7 keV
		839.70		0.020	0.006	0.015	Ac-228 (Th series), 840.4 keV
		860.17		0.075	0.006	0.015	Tl-208 (Th series), 860.6 keV

Table D-16. (continued).

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
Th232	911.21	910.83	0.38	0.458	0.024	0.015	Ac-228 (Th series), 911.2 keV
		933.64		0.030	0.007	0.014	Bi-214 (U series), 934.1 keV
		964.38		0.101	0.009	0.014	Bi-214 (U series) 964.1 keV
		968.60		0.296	0.012	0.014	Ac-228 (Th series), 969.0 keV
U238p	1,001.03	1,000.79	0.24	0.013	0.004	0.013	Pa-234m (U series), 1001.0 keV
		1,119.98		0.204	0.009	0.014	Bi-214 (U series), 1120.3 keV
		1,155.06		0.028	0.005	0.013	Bi-214 (U series), 1155.2 keV
		1,238.02		0.081	0.005	0.014	Bi-214 (U series), 1238.1 keV
		1,280.77		0.018	0.004	0.012	Bi-214 (U series), 1280.96 keV
		1,377.58		0.05655	0.00533	0.00945	Bi-214 (U series), 1377.7 keV
		1,401.53		0.02321	0.00327	0.00887	Bi-214 (U series), 1401.5 keV
Eu152	1,408.01	1,407.86	0.15	0.03177	0.00345	0.00885	Bi-214 (U series), 1408.0 keV
K-40	1,460.83	1,460.83	0.00	2.50200	0.08070	0.00859	K-40, 1460.8 keV
		1,495.90		0.01760	0.00311	0.00604	Ac-228 (Th series), 1495.9 keV
		1,501.55		0.01086	0.00286	0.00613	Ac-228 (Th series), 1501.6 keV
		1,509.52		0.03180	0.00370	0.00669	Bi-214 (U series), 1509.2 keV
		1,538.50		0.00469	0.00218	0.00624	Bi-214 (U series), 1538.5 keV
		1,581.29		0.01139	0.00338	0.00655	Ac-228 (Th series), 1580.5 keV
		1,588.41		0.05658	0.00505	0.00674	Ac-228 (Th series), 1588.2 keV
		1,592.80		0.04131	0.00453	0.00667	2614.5 keV (Tl-208) double escape peak at 1592.5 keV
		1,620.88		0.02787	0.00400	0.00621	Bi-212 (Th series), 1620.5 keV
		1,625.31		0.00438	0.00315	0.00512	below MDA, may be Ac-228 (Th series), 1625.0 keV
		1,630.81		0.02643	0.00405	0.00618	Ac-228 (Th series), 1630.6 keV
		1,638.92		0.00521	0.00305	0.00584	Ac-228 (Th series), 1638.3 keV
		1,661.58		0.01432	0.00229	0.00567	Bi-214 (U series), 1661.3 keV
		1,667.00		0.00575	0.00199	0.00543	near MDA, may be Ac-228, 1666.5 keV
		1,684.83		0.00480	0.00305	0.00524	below MDA, may be Bi-214, 1684.0 keV
		1,730.10		0.04090	0.00364	0.00549	Bi-214 (U series), 1729.6 keV
U238	1,764.49	1,765.04	-0.55	0.21150	0.00909	0.00645	Bi-214 (U series), 1764.5 keV
		1,777.68		0.02440	0.00233	0.00244	barely above MDA, may be spurious
		1,848.08		0.02937	0.00266	0.00541	Bi-214 (U series), 1847.4 keV
		2,103.84		0.06863	0.00727	0.00576	2614.5 keV (Tl-208)

Table D-16. (continued).

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
							escape peak at 2103.5 keV
		2,118.97		0.01562	0.00348	0.00527	Bi-214 (U series), 2118.5 keV
		2,204.36		0.06496	0.00352	0.00566	Bi-214 (U series), 2204.2 keV
		2,447.89		0.02217	0.00234	0.00464	Bi-214 (U series), 2447.9 keV
Th232	2,614.53	2,614.32	0.21	0.62770	0.01912	0.00250	Tl-208 (Th series), 2614.5 keV
		2,755.47		0.00048	0.00040	0.00073	spurious peak at high energy

D-2.1.4 Spectrum DB581000

Gamma rays at 794.6 keV and 1407.9 keV are due to the natural background and not Cs-134 or Eu-152. Peaks due to gamma rays with energies of 99.9, 103.9, 126.1, 147.3, 165.5, 170.9, 208.7, 335.7, 618.9, 688.46, and 721.6 keV indicate the presence of Am-241. The presence of Pu-239 is revealed by peaks corresponding to 204.2, 322.8, 332.8, 368.9, 375.0, 380.3, 392.9, and 413.8 keV. This spectrum also has the signatures of Np-237 at 300.5 and 312.2 keV. A 661.9-keV gamma ray was associated with Cs-137 (661.6 keV) by the analysis program, but the energy residual suggests that the gamma ray is actually the Am-241 gamma ray at 662.4 keV.

A 138.1-keV gamma ray apparently produced a peak in this spectrum. A peak at 138.2 keV also appears in spectrum DB521000.

A peak corresponding to 2222.9 keV is apparently due to 2223.2-keV gamma rays associated with neutron capture by hydrogen. The alpha particle flux in the formation must be so high that neutrons from alpha-n reactions with oxygen exist in numbers sufficient to produce hydrogen capture reactions at detectable levels.

Table D-17. Data for Spectrum DB581000

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
		38.55		0.808	0.408	0.029	probably a spurious low energy peak
		99.88		0.552	0.064	0.055	Am-241 (99.0 keV), Pu-239 (98.8 keV)
Am241	103.00	103.86	-0.86	0.651	0.066	0.055	Am-241 (103.0 keV)
		115.56		0.190	0.139	0.056	Pb-212 (Th series), 115.2 keV (?)
Am241	125.30	126.12	-0.82	0.684	0.159	0.059	Am-241 (125.3 keV)
Pu239	129.30	130.28	-0.98	0.311	0.145	0.056	Pu-239 (129.3 keV)
		138.13		0.221	0.142	0.057	may be spurious; also observed in DB521000
		144.13		0.228	0.143	0.060	Pu-239 (144.2 keV)
		145.14		0.977	0.043	0.067	may be spurious
		147.29		0.287	0.146	0.057	Am-241 (146.6 keV)

Table D-17. (continued).

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
		151.03		0.522	0.033	0.053	may be spurious
		152.30		0.163	0.141	0.057	may be spurious
		156.05		0.530	0.035	0.056	may be spurious
		161.29		0.117	0.140	0.054	Pu-239 (161.4 keV)
		165.49		0.412	0.033	0.052	Am-241 (165.8 keV)
		170.90		0.475	0.038	0.061	Am-241 (169.5 keV), Pu-239 (171.4 keV)
		177.81		0.187	0.030	0.048	may be spurious
		181.69		0.160	0.030	0.048	may be spurious
U235	185.72	186.38	-0.66	0.281	0.043	0.070	Ra-226 (U series), 186.1 keV; U-235, 185.7 keV
		204.21		0.058	0.025	0.052	Pu-239 (203.6 keV)
		208.69		0.407	0.028	0.054	Am-241 (208.0 keV)
		239.17		0.504	0.060	0.046	Pb-212 (Th series), 238.6 keV
		270.60		0.046	0.012	0.039	Ac-228 (Th series), 270.2 keV
		295.61		0.191	0.035	0.038	Pb-212 (Th series), 295.2 keV
Np237	300.34	300.48	-0.14	0.033	0.020	0.033	Np-237 (300.3 keV)
Np237	312.17	312.22	-0.05	0.206	0.017	0.038	Np-237 (312.2 keV)
		322.78		0.079	0.016	0.035	Pu-239 (320.9, 323.8 keV)
		328.46		0.032	0.015	0.034	Ac-228 (Th series), 328.0 keV; Bi-212 (Th series), 328.0 keV
		332.79		0.105	0.016	0.034	Pu-239 (332.8 keV)
		335.74		0.209	0.017	0.035	Am-241 (335.4 keV)
		338.65		0.141	0.016	0.033	Ac-228 (Th series), 338.3 keV
U238	351.92	352.17	-0.25	0.441	0.021	0.033	Pb-214 (U series), 351.9 keV; possibly 352.2 Fe capture gamma
		368.92		0.115	0.021	0.030	Pu-239 (367.1 keV, 368.6 keV)
Pu239	375.05	375.57	-0.52	0.131	0.021	0.031	Pu-239 (375.0 keV)
		380.27		0.024	0.014	0.024	Pu-239 (380.2 keV)
		383.54		0.034	0.019	0.029	Pu-239 (382.8 keV)
		392.93		0.031	0.018	0.028	Pu-239 (392.5 keV)
		409.66		0.020	0.011	0.026	Ac-228 (Th series), 409.5 keV
		413.80		0.093	0.011	0.027	Pu-239 (413.7 keV)
		462.95		0.057	0.010	0.024	Ac-228 (Th series), 463.0 keV

Table D-17. (continued).

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
		510.78		0.346	0.023	0.028	annihilation radiation, 511.0 keV
		562.23		0.016	0.006	0.019	Ac-228 (Th series), 562.5 keV
Th232	583.19	583.09	0.10	0.454	0.020	0.022	Tl-208 (Th series), 583.2 keV
U238	609.31	609.20	0.11	0.564	0.018	0.021	Bi-214 (U series), 609.3 keV
		618.91		0.027	0.010	0.018	Am-241 (619.0 keV)
Cs137	661.66	661.91	-0.25	0.258	0.014	0.018	Am-241 (662.4 keV)
		688.46		0.017	0.005	0.016	Am-241 (688.7 keV)
		721.65		0.085	0.006	0.017	Am-241 (722.0 keV)
		727.06		0.109	0.006	0.017	Bi-212 (Th series), 727.3 keV
		755.15		0.020	0.006	0.016	Ac-228 (Th series), 755.3 keV
		763.25		0.014	0.006	0.014	below MDA, may be Tl-208 (Th series), 763.1 keV
U238p	766.36	767.97	-1.61	0.070	0.007	0.016	Bi-214 (U series) 768.3 keV
		771.92		0.026	0.006	0.015	Ac-228 (Th series), 772.3 keV
		785.37		0.021	0.009	0.015	Pb-214 (U series); 785.9 keV; Bi-212 (Th series) 785.4 keV
Cs134	795.85	794.62	1.23	0.059	1259.000	0.015	Ac-228 (Th series), 794.9 keV
		805.81		0.016	0.005	0.014	Bi-214 (U series), 806.2 keV
		830.26		0.012	0.004	0.014	Ac-228 (Th series), 830.5 keV
		835.26		0.027	0.005	0.014	Ac-228 (Th series), 835.7 keV
		839.63		0.022	0.005	0.014	Ac-228 (Th series), 840.4 keV
		860.15		0.064	0.005	0.015	Tl-208 (Th series), 860.6 keV
		903.99		0.008	0.007	0.012	Ac-228 (Th series), 904.2 keV
Th232	911.21	910.85	0.36	0.407	0.014	0.015	Ac-228 (Th series), 911.2 keV
		933.77		0.047	0.005	0.013	Bi-214 (U series), 934.1 keV
		964.40		0.087	0.005	0.013	Bi-214 (U series) 964.1 keV
		968.58		0.259	0.007	0.014	Ac-228 (Th series), 969.0 keV
U238p	1,001.03	1,000.71	0.32	0.028	0.007	0.013	Pa-234m (U series), 1001.0 keV
		1,031.40		0.009	0.007	0.011	below MDA, may be spurious
		1,033.53		0.006	0.004	0.012	below MDA, may be spurious
		1,066.91		0.006	0.005	0.011	below MDA, may be spurious
		1,094.87		0.067	0.006	0.008	Ac-228 (Th series), 1095.7 keV
		1,119.95		0.204	0.009	0.013	Bi-214 (U series), 1120.3 keV

Table D-17. (continued).

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
		1,154.61		0.023	0.004	0.012	Bi-214 (U series), 1155.2 keV
		1,237.82		0.080	0.005	0.013	Bi-214 (U series), 1238.1 keV
		1,281.93		0.060	0.400	0.011	Bi-214 (U series), 1281.0 keV
		1,377.50		0.055	0.004	0.009	Bi-214 (U series), 1377.7 keV
		1,385.07		0.009	0.003	0.008	Bi-214 (U series), 1385.3 keV
		1,401.44		0.018	0.003	0.008	Bi-214 (U series), 1401.5 keV
Eu152	1,408.01	1,407.94	0.07	0.035	0.003	0.008	Bi-214 (U series), 1408.0 keV
K-40	1,460.83	1,460.75	0.08	2.273	0.029	0.009	K-40, 1460.8 keV
		1,495.81		0.014	0.002	0.006	Ac-228 (Th series), 1495.9 keV
		1,501.72		0.007	0.002	0.006	Ac-228 (Th series), 1501.6 keV
		1,509.20		0.030	0.003	0.007	Bi-214 (U series), 1509.2 keV
		1,538.20		0.007	0.002	0.006	Bi-214 (U series), 1538.5 keV
		1,557.54		0.005	0.002	0.005	Ac-228 (Th series), 1557.1 keV
		1,581.37		0.013	0.004	0.006	Ac-228 (Th series), 1580.5 keV
		1,588.29		0.047	0.006	0.007	Ac-228 (Th series), 1588.2 keV
		1,592.66		0.029	0.006	0.007	2614.5 keV (Tl-208) double escape peak at 1592.5 keV
		1,620.93		0.020	0.004	0.006	Bi-212 (Th series), 1620.5 keV
		1,630.82		0.023	0.005	0.006	Ac-228 (Th series), 1630.6 keV
		1,661.41		0.013	0.003	0.006	Bi-214 (U series), 1661.3 keV
		1,684.77		0.004	0.001	0.005	below MDA, probably spurious
		1,730.06		0.041	0.003	0.006	Bi-214 (U series), 1729.6 keV
U238	1,764.49	1,764.97	-0.48	0.218	0.006	0.005	Bi-214 (U series), 1764.5 keV
		1,848.03		0.029	0.003	0.005	Bi-214 (U series), 1847.4 keV
		2,103.79		0.060	0.008	0.005	2614.5 keV (Tl-208) escape peak at 2103.5 keV
		2,118.61		0.016	0.002	0.005	Bi-214 (U series), 2118.5 keV
		2,204.34		0.067	0.004	0.005	Bi-214 (U series), 2204.2 keV
		2,222.86		0.003	0.002	0.005	H neutron capture gamma ray
		2,293.44		0.005	0.002	0.005	Bi-214 (U series), 2293.4 keV
		2,447.72		0.020	0.002	0.004	Bi-214 (U series), 2447.9 keV
Th232	2,614.53	2,614.37	0.16	0.582	0.026	0.002	Tl-208 (Th series), 2614.5 keV

D-2.1.5 Spectrum DB591000

Like spectrum DB581000, this spectrum has many peaks attributable to the gamma rays of Am-241, Pu-239, and Np-237. The gamma rays at 794.6 keV and 1407.9 keV are due to the natural background and not Cs-134 or Eu-152, and the gamma ray at 661.9 keV is probably the 662.4-keV Am-241 gamma ray and not the 661.6-keV gamma ray of Cs-137.

A peak at 141.5 keV is due to an unknown source. A similar peak at 141.3 keV exists in DB541000. Another peak due to an unknown source is at 234.6 keV. The intensity is below the MDA, but an apparently related peak at 234.8 keV exists in spectrum DB521000. Likewise, peaks at 451.6 and 652.7 keV appear in spectra DB59100 and DB541000; the sources (if they exist) are unknown. An unknown source may have emitted gamma rays of energy 1454.3 keV that account for a weak peak with an intensity just above the MDA. An analogous peak at 1454.5 keV was observed in spectrum DB561000.

Like spectrum DB581000, spectrum DB591000 has a signal at 2,223.6 keV that is attributed to neutron capture by hydrogen.

Table D-18. Data for Spectrum DB591000.

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
		38.68		1.097	0.511	0.023	probably a spurious low energy peak
		40.07		2.935	0.029	0.035	probably a spurious low energy peak
		41.46		0.856	0.522	0.034	probably a spurious low energy peak
		45.63		0.969	0.028	0.042	probably a spurious low energy peak
		60.01		0.100	0.014	0.048	probably a spurious low energy peak
		99.57		2.087	0.377	0.067	Am-241 (99.0 keV), Pu-239 (98.8 keV)
Am241	103	103.54	-0.54	2.290	0.389	0.063	Am-241 (103.0 keV)
		114.61		0.882	0.049	0.079	may be spurious
		115.11		0.386	0.285	0.063	Pb-212 (Th series), 115.2 keV (?)
		118.87		0.570	0.033	0.052	may be spurious
Am241	125.3	125.84	-0.54	1.889	0.369	0.066	Am-241 (125.3 keV)
Pu239	129.3	129.89	-0.59	0.782	0.040	0.063	Pu-239 (129.3 keV)
		136.56		0.467	0.039	0.063	may be spurious
		141.46		0.240	0.273	0.059	unknown; also observed in DB541000
		147.14		0.559	0.293	0.062	Am-241 (146.6 keV)
		160.80		0.382	0.036	0.058	Pu-239 (161.4 keV)
U235	163.33	165.16	-1.83	0.227	0.270	0.061	Am-241 (165.8 keV)

Table D-18. (continued).

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
		170.15		0.442	0.049	0.079	Am-241 (169.5 keV), Pu-239 (171.4 keV)
U235	185.72	186.31	-0.59	0.158	0.017	0.060	Ra-226 (U series), 186.1 keV; U-235, 185.7 keV
		204.22		0.183	0.035	0.056	Pu-239 (203.6 keV)
		208.41		1.229	0.081	0.055	Am-241 (208.0 keV)
		221.77		0.069	0.014	0.049	may be spurious
		234.62		0.029	0.025	0.041	below MDA; also appears in DB521000
		238.97		0.519	0.057	0.052	Pb-212 (Th series), 238.6 keV
		267.68		0.040	0.021	0.041	below MDA, may be spurious
		270.49		0.055	0.021	0.041	Ac-228 (Th series), 270.2 keV
		277.65		0.042	0.020	0.040	Tl-208 (Th series), 277.4 keV
		295.40		0.197	0.090	0.040	Pb-212 (Th series), 295.2 keV
Np237	300.34	300.30	0.04	0.125	0.027	0.044	Np-237 (300.3 keV)
Np237	312.17	312.04	0.13	0.658	0.106	0.040	Np-237 (312.2 keV)
		322.58		0.223	0.085	0.037	Pu-239 (320.9, 323.8 keV)
		327.93		0.036	0.019	0.032	Ac-228 (Th series), 328.0 keV; Bi-212 (Th series), 328.0 keV
		335.50		0.724	0.104	0.037	Am-241 (335.4 keV)
		345.13		0.092	0.074	0.034	Pu-239 (345.0 keV)
U238	351.92	351.96	-0.04	0.389	0.087	0.033	Pb-214 (U series), 351.9 keV
		368.63		0.334	0.060	0.033	Pu-239 (367.1 keV, 368.6 keV)
Pu239	375.05	375.41	-0.36	0.459	0.021	0.032	Pu-239 (375.1 keV)
		380.27		0.076	0.018	0.029	Pu-239 (380.2 keV)
		383.17		0.056	0.048	0.028	Pu-239 (382.8 keV)
		392.72		0.090	0.020	0.029	Pu-239 (392.5 keV)
		413.64		0.261	0.026	0.028	Pu-239 (413.7 keV)
		451.60		0.030	0.007	0.025	unknown; also occurs in DB541000
		462.89		0.052	0.008	0.025	Ac-228 (Th series), 463.0 keV

Table D-18. (continued).

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
		510.67		0.365	0.028	0.028	annihilation radiation, 511.0 keV
Th232	583.19	582.97	0.22	0.437	0.014	0.021	Tl-208 (Th series), 583.2 keV
U238	609.31	609.09	0.22	0.542	0.016	0.020	Bi-214 (U series), 609.3 keV
		618.77		0.076	0.010	0.019	Am-241 (619.0 keV)
		652.70		0.047	0.009	0.018	unknown, also observed in DB541000
Cs137	661.66	661.92	-0.26	0.594	0.017	0.019	probably Am-241 at 662.4 keV
		688.54		0.039	0.006	0.018	Am-241 (688.7 keV)
		702.67		0.012	0.005	0.017	Ac-228, 701.8 keV; Bi-214, 703.1 keV
		721.66		0.253	0.009	0.017	Am-241 (722.0 keV)
		726.93		0.114	0.007	0.016	Bi-212 (Th series), 727.3 keV
U238p	766.36	767.46	-1.10	0.070	0.018	0.016	Bi-214 (U series) 768.3 keV
		785.62		0.032	0.010	0.015	Pb-214 (U series), 785.9 keV; Bi-212 (Th series) 785.4 keV
Cs134	795.85	794.61	1.24	0.056	0.007	0.014	c-228 (Th series), 794.9 keV
		806.02		0.016	0.005	0.013	Bi-214 (U series), 806.2 keV
		835.56		0.023	0.006	0.015	Ac-228 (Th series), 835.7 keV
		839.64		0.016	0.006	0.014	Ac-228 (Th series), 840.4 keV
		860.21		0.070	0.005	0.014	Tl-208 (Th series), 860.6 keV
		904.09		0.009	0.008	0.013	Ac-228 (Th series), 904.2 keV
Th232	911.21	910.85	0.36	0.371	0.011	0.014	Ac-228 (Th series), 911.2 keV
		933.77		0.042	0.005	0.013	Bi-214 (U series), 934.1 keV
		949.63		0.009	0.005	0.013	1460.8-keV (K-40) escape peak (949.8 keV)
		964.38		0.074	0.010	0.013	Bi-214 (U series) 964.1 keV
		968.59		0.230	0.013	0.014	Ac-228 (Th series), 969.0 keV
U238p	1,001.03	1000.75	0.28	0.111	0.009	0.013	Pa-234m (U series), 1001.0 keV
		1079.11		0.012	0.004	0.012	Bi-212 (Th series), 1078.6 keV
		1119.95		0.186	0.013	0.013	Bi-214 (U series), 1120.3 keV

Table D-18. (continued).

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
		1154.85		0.024	0.004	0.012	Bi-214 (U series), 1155.2 keV
		1237.98		0.082	0.005	0.013	Bi-214 (U series), 1238.1 keV
		1280.67		0.020	0.004	0.010	Bi-214 (U series), 1281.0 keV
		1377.65		0.054	0.004	0.009	Bi-214 (U series), 1377.7 keV
		1384.99		0.010	0.003	0.008	Bi-214 (U series), 1385.3 keV
		1401.43		0.023	0.003	0.008	Bi-214 (U series), 1401.5 keV
Eu152	1,408.01	1407.88	0.13	0.031	0.003	0.008	Bi-214 (U series), 1408.0 keV
		1454.31		0.007	0.004	0.006	unknown, observed in DB561000.
K-40	1,460.83	1460.84	-0.01	2.043	0.056	0.008	K-40, 1460.8 keV
		1496.03		0.011	0.003	0.007	Ac-228 (Th series), 1495.9 keV
		1501.99		0.005	0.003	0.006	Ac-228 (Th series), 1501.6 keV
		1509.38		0.030	0.004	0.007	Bi-214 (U series), 1509.2 keV
		1580.78		0.007	0.003	0.004	Ac-228 (Th series), 1580.5 keV
		1583.05		0.011	0.004	0.006	may be spurious
		1588.50		0.050	0.007	0.006	Ac-228 (Th series), 1588.2 keV
		1592.86		0.034	0.006	0.006	2614.5 keV (Tl-208) double escape peak at 1592.5 keV
		1621.05		0.027	0.003	0.006	Bi-212 (Th series), 1620.5 keV
		1630.90		0.024	0.003	0.006	Ac-228 (Th series), 1630.6 keV
		1638.15		0.007	0.002	0.005	Ac-228 (Th series), 1638.3 keV
		1661.57		0.012	0.002	0.006	Bi-214 (U series), 1661.3 keV
		1730.15		0.038	0.003	0.006	Bi-214 (U series), 1729.6 keV
U238	1,764.49	1765.05	-0.56	0.209	0.008	0.006	Bi-214 (U series), 1764.5 keV
		1848.05		0.025	0.003	0.005	Bi-214 (U series), 1847.4 keV
		1936.65		0.004	0.002	0.004	below MDA; 1936.6 keV occurs in SBU cal spectra
		2103.93		0.057	0.006	0.005	2614.5 keV (Tl-208) escape peak at 2103.5 keV
		2118.79		0.014	0.003	0.005	Bi-214 (U series), 2118.5 keV
		2204.30		0.063	0.005	0.005	Bi-214 (U series), 2204.2 keV

Table D-18. (continued).

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
		2223.56		0.010	0.002	0.005	H capture gamma ray
		2239.06		0.003	0.002	0.004	Cr capture gamma ray (?)
		2293.60		0.004	0.002	0.005	Bi-214 (U series), 2293.4 keV
		2447.72		0.020	0.002	0.004	Bi-214 (U series), 2447.9 keV
Th232	2,614.53	2614.32	0.21	0.525	0.021	0.003	Tl-208 (Th series), 2614.5 keV

D-2.2 Analysis Results for Borehole P6-PU-2

Five spectra were acquired from this borehole. The names of the spectra and the associated depths are as follows.

Spectrum Name	Depth
DB501000	20.06 ft
DB511000	16.5 ft
DB521000	16.0 ft
DB531000	15.5 ft
DB541000	15.0 ft

D-2.2.1 Spectrum DB501000

As occurred with spectra from borehole P6-PU-1, the analysis program assigned gamma rays with energies 795.0 keV and 1408.0 keV to Cs-134 and Eu-152, but the two gamma rays are more likely part of the natural background. No peaks that could be unambiguously associated with man-made sources are evident in spectrum DB501000.

Table D-19. Data for Spectrum DB501000

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
		127.26		0.042	0.035	0.058	below MDA, probably spurious
U235	185.72	185.88	-0.16	0.048	0.032	0.05249	Ra-226 (U series), 186.1 keV; U-235, 185.7 keV
		238.59		0.629	0.034	0.054	Pb-212 (Th series), 238.6 keV
		270.52		0.039	0.025	0.041	below MDA; Ac-228 (Th series), at 270.2 keV

Table D-19. (continued).

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
		294.61		0.166	14.890	0.035	Pb-214 (U series), 295.2 keV (large uncertainty)
		338.34		0.135	0.021	0.034	Ac-228 (Th series), 338.3 keV
U238	351.92	351.86	0.06	0.416	0.023	0.03616	Pb-214 (U series), 351.9 keV
		463.04		0.056	0.015	0.025	Ac-228 (Th series), 463.0 keV
		510.80		0.295	0.017	0.026	annihilation radiation (511.0 keV)
Th232	583.19	583.22	-0.03	0.446	0.017	0.02562	Tl-208 (Th series), 583.2 keV
U238	609.31	609.37	-0.06	0.553	0.016	0.02149	Bi-214 (U series), 609.3 keV
		665.44		0.013	0.010	0.017	below MDA; Bi-214 (U series), 665.4 keV
		727.27		0.103	0.013	0.020	Ac-228, 726.9 keV; Bi-212 (Th series), 727.3 keV
		755.38		0.025	0.010	0.016	Ac-228 (Th series), 755.3 keV
		768.27		0.031	0.010	0.017	Bi-214 (U series), 768.3 keV
		785.62		0.019	0.007	0.015	Pb-214 (U series), 785.9 keV; Bi-212 (Th series) 785.4 keV
Cs134	795.85	795.02	0.83	0.064	0.008	0.01499	Ac-228 (Th series), 794.9 keV
		806.28		0.016	0.010	0.016	below MDA; Bi-214 (U series), 806.2 keV
		830.98		0.012	0.006	0.014	below MDA; Ac-228 (Th series), 830.5 keV
		836.00		0.022	0.006	0.014	Ac-228 (Th series), 835.7 keV
		860.55		0.064	0.009	0.015	Tl-208 (Th series), 860.6 keV
Th232	911.21	911.16	0.05	0.390	0.013	0.01807	Ac-228 (Th series), 911.2 keV
		934.09		0.042	0.010	0.017	Bi-214 (U series), 934.1 keV
		949.64		0.017	0.008	0.014	1460.8 keV (K-40) escape peak (949.8 keV)
		964.65		0.074	0.005	0.014	Bi-214 (U series) 964.1 keV
		968.91		0.242	0.007	0.014	Ac-228 (Th series), 969.0 keV
		980.89		0.009	0.008	0.013	below MDA, probably spurious

Table D-19. (continued).

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
U238p	1,001.03	1,001.00	0.03	0.028	0.007	0.01051	Pa-234m (U series), 1001.0 keV
		1,078.62		0.009	0.007	0.011	below MDA; Bi-212 (Th series) 1078.6 keV
		1,120.16		0.201	0.010	0.015	Bi-214 (U series), 1120.3 keV
		1,155.13		0.035	0.009	0.015	Bi-214 (U series), 1155.2 keV
		1,208.27		0.008	0.007	0.012	below MDA; Bi-214 (U series), 1207.7 keV
		1,237.63		0.072	0.008	0.013	Bi-214 (U series), 1238.1 keV
		1,281.04		0.012	0.007	0.011	Bi-214 (U series), 1281.0 keV
		1,377.51		0.060	0.004	0.010	Bi-214 (U series), 1377.7 keV
		1,385.35		0.011	0.003	0.009	Bi-214 (U series), 1385.3 keV
		1,401.01		0.019	0.003	0.009	Bi-214 (U series), 1401.5 keV
Eu152	1,408.01	1,408.04	-0.03	0.029	0.003	0.008904	Bi-214 (U series), 1408.0 keV
K-40	1,460.83	1,460.70	0.13	2.114	0.018	0.01043	K-40, 1460.8 keV
		1,495.94		0.011	0.004	0.007	Ac-228 (Th series), 1495.9 keV
		1,501.66		0.005	0.003	0.007	below MDA; Ac-228 (Th series), 1501.6 keV
		1,509.35		0.026	0.004	0.007	Bi-214 (U series), 1509.2 keV
		1,554.93		0.005	0.003	0.006	below MDA, probably spurious
		1,581.57		0.011	0.004	0.006	Ac-228 (Th series), 1580.5 keV
		1,588.14		0.048	0.006	0.006	Ac-228 (Th series), 1588.2 keV
		1,592.57		0.038	0.005	0.007	2614.5 keV (Tl-208) double escape peak (1592.5 keV)
		1,598.83		0.006	0.003	0.005	Bi-214 (U series), 1599.3 keV
		1,620.82		0.022	0.004	0.006	Bi-212 (Th series), 1620.5 keV
		1,630.38		0.030	0.005	0.006	Ac-228 (Th series), 1630.6 keV
		1,660.97		0.014	0.004	0.006	Bi-214 (U series), 1661.3 keV
		1,729.64		0.037	0.004	0.006	Bi-214 (U series), 1729.6 keV
U238	1,764.49	1,764.59	-0.10	0.222	0.007	0.006213	Bi-214 (U series), 1764.5 keV
		1,793.53		-0.001	0.012	0.004	below MDA, negative intensity,

Table D-19. (continued).

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
							most likely spurious
		1,838.33		0.004	0.002	0.005	Bi-214 (U series), 1838.4 keV
		1,847.75		0.028	0.003	0.005	Bi-214 (U series), 1847.4 keV
		1,872.52		0.005	0.002	0.005	Bi-214 (U series), 1873.2 keV
		1,876.32		0.004	0.002	0.005	below MDA, probably spurious
		1,937.14		0.003	0.003	0.004	below MDA; 1936.6 keV occurs in SBU cal spectra
		2,103.43		0.070	0.005	0.006	2614.5 keV (Tl-208) escape peak (2103.5 keV)
		2,118.16		0.018	0.003	0.005	Bi-214 (U series), 2118.6 keV
		2,203.58		0.069	0.005	0.006	Bi-214 (U series), 2204.2 keV
		2,447.35		0.021	0.003	0.005	Bi-214 (U series), 2447.9 keV
Th232	2,614.53	2,614.49	0.04	0.558	0.009	0.002879	Tl-208 (Th series), 2614.5 keV
		2,805.18		0.0008	0.0007	0.0010	below MDA, probably spurious

D-2.2.2 Spectrum DB511000

Gamma rays that the analysis program associated with Cs-134 and Eu-152 are actually part of the natural background. There is a weak peak of unknown origin corresponding to 1452.5 keV; the intensity is below the MDA in this spectrum, but peaks exist at 1452.8 keV and 1451.3 keV in spectra DB521000 and DB541000.

Spectrum DB511000 has no peaks that could be unambiguously associated with man-made sources.

Table D-20. Data for Spectrum DB511000.

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
		40.2		2.283	0.024	0.025	probably a spurious low energy peak
		46.48		1.492	0.026	0.035	probably a spurious low energy peak
		55.05		0.389	0.024	0.037	probably a spurious low energy peak
		58.48		0.090	0.019	0.031	probably a spurious low energy peak
U235	185.72	185.85	-0.13	0.054	0.028	0.047	Ra-226 (U series), 186.1 keV; U-235, 185.7 keV

Table D-20. (continued)

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
		238.57		0.618	0.031	0.049	Pb-212 (Th series), 238.6 keV
		270.27		0.052	0.023	0.037	Ac-228 (Th series), 270.2 keV
		295.13		0.175	0.024	0.039	Pb-214 (U series), 295.2 keV
		300.14		0.031	0.022	0.036	Pb-212 (Th series), 300.1 keV
		327.92		0.055	0.026	0.043	Ac-228 (Th series), 328.0 keV; Bi-212 (Th series), 328.0 keV
		338.29		0.164	0.022	0.035	Ac-228 (Th series), 338.3 keV
U238	351.92	351.87	0.05	0.416	0.021	0.032	Pb-214 (U series), 351.9 keV
		455.37		0.018	0.017	0.027	Bi-214 (U series), 454.8 keV
		462.74		0.062	0.021	0.034	Ac-228 (Th series), 463.0 keV
		510.79		0.348	0.020	0.032	annihilation radiation, 511.0 keV
		562.71		0.019	0.013	0.022	Ac-228 (Th series), 562.5 keV
Th232	583.19	583.2	-0.01	0.470	0.018	0.026	Tl-208 (Th series), 583.2 keV
U238	609.31	609.33	-0.02	0.550	0.017	0.024	Bi-214 (U series), 609.3 keV
		665.7		0.011	0.010	0.017	Bi-214 (U series) 665.4 keV
		727.3		0.101	0.013	0.020	Bi-212 (Th series), 727.3 keV
		755.25		0.016	0.010	0.016	Ac-228 (Th series), 755.3 keV
		768.3	-1.94	0.068	0.013	0.021	Bi-214 (U series) 768.3 keV
		781.29		0.008	0.008	0.013	Ac-228 (Th series), 782.1 keV
		785.44		0.038	0.010	0.017	Pb-214 (U series), 785.9 keV; Bi-212 (Th series) 785.4 keV
Cs134	795.85	795.02	0.83	0.074	0.012	0.019	Ac-228 (Th series), 794.9 keV
		860.52		0.077	0.010	0.016	Tl-208 (Th series), 860.6 keV
Th232	911.21	911.14	0.07	0.421	0.014	0.019	Ac-228 (Th series), 911.2 keV
		933.82		0.045	0.009	0.015	Bi-214 (U series), 934.1 keV
		949.63		0.012	0.010	0.016	2614.5 keV (K-40) escape peak (949.8 keV)
		964.82		0.097	0.009	0.013	Bi-214 (U series) 964.1 keV
		968.84		0.277	0.010	0.013	Ac-228 (Th series), 969.0 keV
U238p	1001.03	1001.31	-0.28	0.010	0.008	0.013	Pa-234m (U series), 1001.0 keV

Table D-20. (continued)

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
		1078.12		0.014	0.009	0.014	below MDA, Bi-212 (Th series) 1078.6 keV
		1120.07		0.190	0.011	0.016	Bi-214 (U series), 1120.3 keV
		1155.1		0.022	0.010	0.016	Bi-214 (U series), 1155.2 keV
		1206.1		0.011	0.008	0.013	Bi-214 (U series), 1207.7 keV
		1237.84		0.085	0.012	0.018	Bi-214 (U series), 1238.1 keV
		1281.04		0.014	0.007	0.012	Bi-214 (U series), 1281.0 keV
		1377.41		0.054	0.007	0.011	Bi-214 (U series), 1377.7 keV
		1385.26		0.010	0.005	0.009	Bi-214 (U series), 1385.3 keV
		1401		0.021	0.006	0.010	Bi-214 (U series), 1401.5 keV
Eu152	1408.01	1407.59	0.42	0.033	0.006	0.009	Bi-214 (U series), 1408.0 keV
		1452.48		0.004	0.004	0.006	below MDA, unknown
K-40	1460.83	1460.56	0.27	2.514	0.020	0.010	K-40, 1460.8 keV
		1495.5		0.014	0.004	0.007	Ac-228 (Th series), 1495.9 keV
		1500.87		0.005	0.004	0.006	below MDA, Ac-228 (Th series), 1501.6 keV
		1509.34		0.036	0.006	0.008	Bi-214 (U series), 1509.2 keV
		1582.18		0.012	0.004	0.006	Ac-228 (Th series), 1580.5 keV
		1587.91		0.053	0.004	0.006	Ac-228 (Th series), 1588.2 keV
		1591.94		0.050	0.005	0.007	2614.5 keV (Tl-208) double escape peak (1592.5 keV)
		1620.76		0.023	0.005	0.008	Bi-212 (Th series), 1620.5 keV
		1630.4		0.024	0.004	0.007	Ac-228 (Th series), 1630.6 keV
		1637.69		0.005	0.004	0.006	Ac-228 (Th series), 1638.3 keV
		1660.91		0.014	0.004	0.007	Bi-214 (U series), 1661.3 keV
		1729.44		0.033	0.005	0.007	Bi-214 (U series), 1729.6 keV
U238	1764.49	1764.49	0	0.215	0.007	0.008	Bi-214 (U series), 1764.5 keV
		1838.19		0.004	0.003	0.005	Bi-214 (U series), 1838.4 keV
		1847.41		0.028	0.005	0.007	Bi-214 (U series), 1847.4 keV
		2103.14		0.081	0.005	0.007	2614.5 keV (Tl-208)

Table D-20. (continued)

Library ID	Library Energy (keV)	Measured Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
							escape peak (2103.5 keV)
		2203.54		0.065	0.005	0.007	Bi-214 (U series), 2204.2 keV
		2447.36		0.022	0.004	0.005	Bi-214 (U series), 2447.9 keV
Th232	2614.53	2614.12	0.41	0.637	0.010	0.002878	Tl-208 (Th series), 2614.5 keV
		2692.74		0.000629	0.000539	0.000836	below MDA, probably spurious
		2741.9		0.000586	0.000458	0.000683	below MDA, probably spurious

D-2.2.3 Spectrum DB521000

As observed with many other spectra, gamma rays at 795.0 keV and 1407.6 keV are mis-identified. Spectrum DB521000 has a peak at 1452.8 keV for which the source (if it exists) is unknown. This is not dismissed as a spurious peak because peaks at 1452.5 keV and 1451.3 keV exist in spectra DB511000 and DB541000.

A weak peak at 138.2 keV has an intensity below the MDA. The source (if it exists) is unknown. The peak may not be spurious because a more intense peak at 138.1 keV is present in spectrum DB581000. Another peak due to an unknown source is at 234.8 keV. The intensity is below the MDA, but an apparently related peak at 234.6 keV exists in spectrum DB591000.

Spectrum DB521000 has a weak peak corresponding to 129.6 keV. The peak could be associated with the 129.3-keV Pu-239 gamma ray, but this is far from certain because the peak intensity is below the MDA and the signal could be due to the129.1-keV gamma ray from naturally occurring Ac-228. Otherwise, no peaks that could be unambiguously associated with man-made sources appear in spectrum DB521000.

Table D-21. Data for Spectrum DB521000

Library ID	Library Energy (keV)	Calculated Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
		40.68		0.8136	0.4095	0.0175	probably a spurious low energy peak
		41.26		2.1930	0.0211	0.0196	probably a spurious low energy peak
		46.31		0.6884	0.4204	0.0257	probably a spurious low energy peak
		47.55		1.3500	0.0220	0.0283	probably a spurious low energy peak
		49.29		0.5865	0.4177	0.0294	probably a spurious low energy peak
		55.36		0.6304	0.0216	0.0321	probably a spurious low energy peak
		55.70		0.3736	0.4115	0.0349	probably a spurious low energy peak
		59.83		0.6208	0.0262	0.0403	probably a spurious low energy peak
		65.27		0.2260	0.0206	0.0328	probably a spurious low energy peak

Table D-21. (continued).

Library ID	Library Energy (keV)	Calculated Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
		68.75		0.1518	0.0227	0.0366	probably a spurious low energy peak
		73.07		0.0927	0.0233	0.0379	probably a spurious low energy peak
Pu239	129.30	129.55	-0.25	0.0260	0.0247	0.0534	Pu-239 (? below MDA); an Ac-228 (Th series) gamma exists at 129.1 keV
		132.14		0.0621	0.0346	0.0568	Th-228 (Th series), 131.6 keV
		138.20		0.0370	0.0251	0.0540	below MDA; also observed in DB581000
U235	185.72	186.54	-0.82	0.0912	0.0151	0.0505	Ra-226 (U series), 186.1 keV; U-235, 185.7 keV
		231.21		0.0428	0.0481	0.0438	below MDA, may be spurious
		234.76		0.0480	0.0229	0.0376	unknown; also observed in DB591000
		239.25		0.5667	0.0579	0.0477	Pb-212 (Th series), 238.6 keV
		270.73		0.0531	0.0167	0.0404	Ac-228 (Th series), 270.2 keV
		295.67		0.2052	0.0119	0.0392	Pb-212 (Th series), 295.2 keV
		300.68		0.0581	0.0106	0.0364	Pb-212 (Th series), 300.1 keV
		328.39		0.0381	0.0099	0.0341	Ac-228 (Th series), 328.0 keV; Bi-212 (Th series), 328.0 keV
		338.62		0.1660	0.0106	0.0330	Ac-228 (Th series), 338.3 keV
U238	351.92	352.18	-0.26	0.4158	0.0205	0.0331	Pb-214 (U series), 351.9 keV
		409.90		0.0303	0.0081	0.0274	Ac-228 (Th series), 409.5 keV
		438.98		0.0246	0.0100	0.0240	Ac-228 (Th series), 440.4 keV (?)
		462.96		0.0759	0.0079	0.0259	Ac-228 (Th series), 463.0 keV
		510.75		0.3619	0.0280	0.0285	annihilation radiation, 511.0 keV
Th232	583.19	583.02	0.17	0.4895	0.0237	0.0225	Tl-208 (Th series), 583.2 keV
U238	609.31	609.12	0.19	0.5584	0.0277	0.0214	Bi-214 (U series), 609.3 keV
		665.14		0.0212	0.0058	0.0181	Bi-214 (U series) 665.4 keV
		702.79		0.0089	0.0083	0.0163	Ac-228, 701.8 keV; Bi-214, 703.1 keV
		726.97		0.1158	0.0094	0.0188	Bi-212 (Th series), 727.3 keV

Table D-21. (continued).

Library ID	Library Energy (keV)	Calculated Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
		755.25		0.0148	0.0035	0.0165	Ac-228 (Th series), 755.3 keV
		767.95		0.0497	0.0091	0.0172	Bi-214 (U series) 768.3 keV
		771.94		0.0235	0.0084	0.0169	Ac-228 (Th series), 772.3 keV
		785.45		0.0245	0.0081	0.0161	Pb-214 (U series), 785.9 keV; Bi-212 (Th series) 785.4 keV
Cs134	795.85	794.59	1.26	0.0745	0.0089	0.0163	Ac-228 (Th series), 794.9 keV
		835.41		0.0193	0.0103	0.0153	Ac-228 (Th series), 835.7 keV
		840.00		0.0152	0.0086	0.0140	Ac-228 (Th series), 840.4 keV
		860.09		0.0820	0.0057	0.0159	Tl-208 (Th series), 860.6 keV
		904.06		0.0145	0.0047	0.0141	Ac-228 (Th series), 904.2 keV
Th232	911.21	910.73	0.48	0.4683	0.0094	0.0160	Ac-228 (Th series), 911.2 keV
		933.51		0.0373	0.0067	0.0144	Bi-214 (U series), 934.1 keV
		949.09		0.0114	0.0045	0.0143	1460.8 keV (K-40) escape peak (949.8 keV)
		964.24		0.0869	0.0088	0.0155	Bi-214 (U series) 964.1 keV
		968.47		0.2806	0.0121	0.0154	Ac-228 (Th series), 969.0 keV
		1,119.74		0.1933	0.0068	0.0150	Bi-214 (U series), 1120.3 keV
		1,154.91		0.0217	0.0044	0.0137	Bi-214 (U series), 1155.2 keV
		1,237.70		0.0885	0.0056	0.0144	Bi-214 (U series), 1238.1 keV
		1,280.77		0.0156	0.0049	0.0116	Bi-214 (U series), 1281.0 keV
		1,377.32		0.0503	0.0041	0.0102	Bi-214 (U series), 1377.7 keV
		1,401.19		0.0196	0.0042	0.0090	Bi-214 (U series), 1401.5 keV
Eu152	1,408.01	1,407.77	0.24	0.0318	0.0047	0.0096	Bi-214 (U series), 1408.0 keV
		1,452.82		0.0073	0.0042	0.0068	unknown; observed in DB511000 and DB541000
K-40	1,460.83	1,460.63	0.20	2.5610	0.1091	0.0094	K-40, 1460.8 keV
		1,495.59		0.0158	0.0034	0.0070	Ac-228 (Th series), 1495.9 keV
		1,501.61		0.0071	0.0030	0.0069	Ac-228 (Th series), 1501.6 keV
		1,509.14		0.0292	0.0037	0.0070	Bi-214 (U series), 1509.2 keV
		1,556.43		0.0054	0.0021	0.0059	Ac-228 (Th series), 1557.1 keV

Table D-21. (continued).

Library ID	Library Energy (keV)	Calculated Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
		1,581.48		0.0098	0.0037	0.0065	Ac-228 (Th series), 1580.5 keV
		1,588.16		0.0540	0.0055	0.0071	Ac-228 (Th series), 1588.2 keV
		1,592.53		0.0440	0.0052	0.0068	2614.5 keV (Tl-208) double escape peak (1592.5 keV)
		1,620.73		0.0249	0.0042	0.0065	Bi-212 (Th series), 1620.5 keV
		1,630.52		0.0295	0.0044	0.0064	Ac-228 (Th series), 1630.6 keV
		1,661.47		0.0104	0.0029	0.0061	Bi-214 (U series), 1661.3 keV
		1,694.57		0.0048	0.0024	0.0056	probably spurious
		1,711.70		0.0035	0.0019	0.0051	below MDA, probably spurious
		1,729.73		0.0357	0.0030	0.0061	Bi-214 (U series), 1729.6 keV
U238	1,764.49	1,764.82	-0.33	0.2028	0.0120	0.0063	Bi-214 (U series), 1764.5 keV
		1,847.96		0.0257	0.0034	0.0057	Bi-214 (U series), 1847.4 keV
		2,103.71		0.0734	0.0084	0.0059	2614.5 keV (Tl-208) escape peak (2103.5 keV)
		2,118.77		0.0136	0.0052	0.0056	Bi-214 (U series), 2118.5 keV
		2,204.13		0.0626	0.0061	0.0062	Bi-214 (U series), 2204.2 keV
		2,256.68		0.0028	0.0028	0.0048	below MDA, probably spurious
		2,447.47		0.0184	0.0031	0.0048	Bi-214 (U series), 2447.9 keV
		2,600.59		0.0017	0.0012	0.0020	below MDA, probably spurious
		2,603.76		0.0035	0.0010	0.0012	probably spurious
Th232	2,614.53	2,614.42	0.11	0.6159	0.0551	0.0023	Tl-208 (Th series), 2614.5 keV

D-2.2.4 Spectrum DB531000

Gamma rays at 794.7 keV and 1408.0 keV are mis-identified, as usual. There are two weak peaks corresponding to 102.5 keV and 129.9 keV. The analysis program associated these peaks with the 103.0-keV gamma ray of Am-241 and the 129.3-keV gamma ray of Pu-239. These identifications are far from certain because both peak intensities are below the corresponding MDAs. Additionally, there is no confirming Am-241 signal at 99.0 keV, and the 129.9-keV signal may be mostly due to the 129.1-keV gamma ray of naturally occurring Ac-228.

An unknown gamma ray source produced a peak at 1,538.4 keV. Analogous peaks were also observed in spectra DB551000, DB561000, DB571000, and DB581000. A peak corresponding to 1809.6 keV has an intensity below the MDA, but an analogous peak at 1809.3 keV is also seen in spectrum DB541000. The gamma ray source (if it exists) is unknown.

Spectrum DB531000 has a peak corresponding to 2,223.6 keV, which is apparently due to the 2,223.2-keV hydrogen neutron capture gamma ray. This is surprising in consideration of the fact that the spectrum has no definite signals due to man-made alpha particle emitters. Spectrum DB541000, which was acquired six inches higher than DB31000, has a more intense peak at 2,223.5 keV and also has Am-241 and Pu-239 signatures. It is possible that elevated alpha fluxes at the higher depth promote alpha-n reactions with oxygen, and that the hydrogen neutron capture gamma rays have sufficient energy to penetrate the approximately six inches of intervening material. The gamma rays from Am-241 and Pu-239 are too low in energy to penetrate as far.

Table D-22. Data for Spectrum DB531000

Library ID	Library Energy (keV)	Calculated Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
		40.29		0.685	0.700	0.023	probably a spurious low energy peak
		40.89		2.542	0.028	0.034	probably a spurious low energy peak
		48.13		0.640	0.026	0.040	probably a spurious low energy peak
Am241	103.00	102.47	0.53	0.036	0.018	0.047	below MDA, no confirming gamma at 99.0 keV, may be spurious
Pu239	129.30	129.92	-0.62	0.034	0.021	0.053	Pu-239 (? below MDA); an Ac-228 (Th series) gamma exists at 129.1 keV
U235	185.72	186.43	-0.71	0.074	0.010	0.050	Ra-226 (U series), 186.1 keV; U-235, 185.7 keV
		238.97		0.532	0.039	0.045	Pb-212 (Th series), 238.6 keV
		253.47		0.032	0.015	0.039	below MDA, Tl-208 (Th series), 252.6 keV
		295.37		0.175	0.019	0.037	Pb-212 (Th series), 295.2 keV
		300.41		0.026	0.022	0.036	Pb-212 (Th series), 300.1 keV
		328.10		0.029	0.010	0.033	Ac-228 (Th series), 328.0 keV; Bi-212 (Th series), 328.0 keV
		338.36		0.155	0.017	0.032	Ac-228 (Th series), 338.3 keV
U238	351.92	351.94	-0.02	0.379	0.016	0.033	Pb-214 (U series), 351.9 keV
		409.31		0.024	0.014	0.027	Ac-228 (Th series), 409.5 keV
		462.73		0.069	0.011	0.024	Ac-228 (Th series), 463.0 keV
		510.61		0.443	0.031	0.030	annihilation radiation, 511.0 keV
Th232	583.19	582.97	0.22	0.479	0.007	0.022	Tl-208 (Th series), 583.2 keV

Table D-22. (continued).

Library ID	Library Energy (keV)	Calculated Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
U238	609.31	609.09	0.22	0.517	0.010	0.021	Bi-214 (U series), 609.3 keV
		727.01		0.123	0.007	0.017	Bi-212 (Th series), 727.3 keV
		755.51		0.019	0.005	0.016	Ac-228 (Th series), 755.3 keV
U238p	766.36	768.02	-1.66	0.059	0.006	0.017	Bi-214 (U series) 768.3 keV
		772.14		0.028	0.005	0.016	Ac-228 (Th series), 772.3 keV
Cs134	795.85	794.72	1.13	0.078	0.006	0.016	Ac-228 (Th series), 794.9 keV
		806.06		0.016	0.005	0.015	Bi-214 (U series), 806.2 keV
		835.52		0.029	0.007	0.015	Ac-228 (Th series), 835.7 keV
		839.79		0.021	0.006	0.015	Ac-228 (Th series), 840.4 keV
		860.17		0.085	0.006	0.016	Tl-208 (Th series), 860.6 keV
		903.72		0.011	0.009	0.014	Ac-228 (Th series), 904.2 keV
Th232	911.21	910.86	0.35	0.462	0.013	0.015	Ac-228 (Th series), 911.2 keV
		933.67		0.038	0.005	0.014	Bi-214 (U series), 934.1 keV
		950.00		0.017	0.004	0.013	2614.5 keV (K-40) escape peak (949.8 keV)
		964.44		0.092	0.008	0.015	Bi-214 (U series) 964.1 keV
		968.62		0.285	0.011	0.015	Ac-228 (Th series), 969.0 keV
U238p	1,001.03	1,000.64	0.39	0.016	0.006	0.014	Pa-234m (U series), 1001.0 keV
		1,078.27		0.012	0.007	0.012	Bi-212 (Th series) 1078.6 keV
		1,080.56		0.038	0.035	0.013	indistinct, bad background fit, probably spurious
		1,095.99		0.008	0.004	0.013	Ac-228 (Th series), 1095.6 leV
		1,119.97		0.191	0.011	0.015	Bi-214 (U series), 1120.3 keV
		1,154.83		0.018	0.007	0.013	Bi-214 (U series), 1155.2 keV
		1,207.19		0.010	0.005	0.013	Bi-214 (U series), 1207.7 keV
		1,237.80		0.076	0.014	0.014	Bi-214 (U series), 1238.1 keV
		1,280.69		0.012	0.004	0.012	Bi-214 (U series), 1281.0 keV
		1,377.59		0.055	0.004	0.010	Bi-214 (U series), 1377.7 keV
		1,385.09		0.014	0.003	0.009	Bi-214 (U series), 1385.3 keV

Table D-22. (continued).

Library ID	Library Energy (keV)	Calculated Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
		1,401.29		0.018	0.003	0.009	Bi-214 (U series), 1401.5 keV
Eu152	1,408.01	1,407.99	0.02	0.031	0.004	0.010	Bi-214 (U series), 1408.0 keV
K-40	1,460.83	1,460.83	0.00	2.587	0.054	0.010	K-40, 1460.8 keV
		1,495.95		0.010	0.005	0.007	Ac-228 (Th series), 1495.9 keV
		1,501.35		0.008	0.004	0.007	Ac-228 (Th series), 1501.6 keV
		1,509.46		0.027	0.006	0.008	Bi-214 (U series), 1509.2 keV
		1,538.43		0.005	0.003	0.007	unknown also observed in DB551000, DB561000, DB571000, DB581000
		1,581.74		0.015	0.005	0.007	Ac-228 (Th series), 1580.5 keV
		1,588.33		0.055	0.007	0.008	Ac-228 (Th series), 1588.2 keV
		1,592.78		0.045	0.006	0.007	2614.5 keV (Tl-208) double escape peak (1592.5 keV)
		1,621.02		0.025	0.004	0.007	Bi-212 (Th series), 1620.5 keV
		1,630.97		0.029	0.003	0.007	Ac-228 (Th series), 1630.6 keV
		1,638.52		0.011	0.002	0.006	Ac-228 (Th series), 1638.3 keV
		1,661.66		0.012	0.004	0.006	Bi-214 (U series), 1661.3 keV
		1,730.25		0.040	0.005	0.006	Bi-214 (U series), 1729.6 keV
U238	1,764.49	1,765.04	-0.55	0.205	0.009	0.007	Bi-214 (U series), 1764.5 keV
		1,809.56		0.003	0.002	0.006	below MDA, also observed in DB541000
		1,848.00		0.028	0.003	0.006	Bi-214 (U series), 1847.4 keV
		2,103.92		0.075	0.006	0.006	2614.5 keV (Tl-208) escape peak (2103.5 keV)
		2,118.73		0.018	0.004	0.006	Bi-214 (U series), 2118.5 keV
		2,204.37		0.062	0.004	0.006	Bi-214 (U series), 2204.2 keV
		2,223.59		0.016	0.002	0.006	H neutron capture gamma ray
		2,293.07		0.004	0.002	0.006	below MDA, Bi-214 (U series), 2293.4 keV
		2,447.45		0.019	0.002	0.005	Bi-214 (U series), 2447.9 keV

Table D-22. (continued).

Library ID	Library Energy (keV)	Calculated Energy (keV)	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
		2,606.54		0.002	0.001	0.003	below MDA, multiplet on 2614.5-keV gamma peak
Th232	2,614.53	2,614.32	0.21	0.669	0.010	0.003	Tl-208 (Th series), 2614.5 keV
		2,775.05		0.008	0.005	0.004	indistinct, bad background fit, probably spurious

D-2.2.5 Spectrum DB541000

Like spectra DB581000 and DB591000, this spectrum has many peaks associated with Am-241 and Pu-239 gamma rays. However, no signals attributable to Np-237 are evident. The gamma rays at 794.6 keV and 1407.9 keV are due to the natural background and not Cs-134 or Eu-152, and the gamma ray at 662.2 keV is probably the 662.4-keV Am-241 gamma ray and not the 661.6-keV gamma ray of Cs-137.

The 1001.0-keV Pa-234m gamma ray peak in this spectrum has an elevated intensity relative to the analogous peaks in the nine other spectra from P6-PU-1 and P6-PU-2. This suggests that the U-238 concentration may be anomalously high, such as would be the case if purified uranium were present.

An unknown source apparently emits 141.3-keV gamma rays. The intensity of the peak is below the MDA, but the peak is not regarded as spurious because a peak at 141.5 keV exists in spectrum DB591000. Other peaks of unknown origin appear at 451.5 keV and 652.3 keV. The 652.3-keV peak intensity is below the MDA, but neither peak is dismissed as spurious because peaks at 451.6 keV and 652.7 keV occur in spectrum DB591000. Another unknown source of gamma rays produced a peak at 1451.3 keV at an intensity just above the MDA. Analogous peaks at 1452.5 keV and 1452.8 keV were observed in spectra DB511000 and DB521000. An 1809.3-keV gamma ray of unknown origin apparently also accounted for the peak at 1809.6 keV in spectrum DB531000.

A peak at 1274.2 keV was identified as Eu-154 by the analysis program. This is probably an incorrect identification because the spectrum has no peaks corresponding to the 723.3- or 123.1-keV gamma rays of Eu-154. However, the origin of the gamma ray (if it exists) is unknown.

Spectrum DB541000 has a peak at 2223.5 keV that is attributed to the 2223.2-keV hydrogen neutron capture gamma ray.

Table D-23. Data for Spectrum DB541000

Library ID	Library Energy (keV)	Calculated Energy (keV	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
		48.62		0.029	0.022	0.061	probably a spurious low energy peak
Pu239	129.30	130.03	-0.73	0.169	0.028	0.077	probably Pu-239; an Ac-228 (Th series) gamma exists at 129.1 keV
		141.27		0.095	0.061	0.100	below MDA;

Table D-23. (continued).

Library ID	Library Energy (keV)	Calculated Energy (keV	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
							also observed in DB591000
		146.97		0.045	0.027	0.073	below MDA, probably spurious
		149.46		0.024	0.027	0.068	below MDA, probably spurious
U235	185.72	186.31	-0.59	0.141	0.013	0.071	Ra-226 (U series), 186.1 keV; U-235, 185.7 keV
		204.20		0.094	0.024	0.067	Pu-239 (203.6 keV)
		208.66		0.208	0.024	0.062	Am-241 (208.0 keV)
		239.13		0.445	0.052	0.059	Pb-212 (Th series), 238.6 keV
		295.53		0.151	0.024	0.048	Pb-212 (Th series), 295.2 keV
		332.94		0.176	0.059	0.040	Pu-239 (332.8 keV)
		335.73		0.169	0.024	0.040	Am-241 (335.4 keV)
		338.49		0.084	0.055	0.039	Ac-228 (Th series), 338.3 keV
		345.15		0.141	0.025	0.040	Pu-239 (345.0 keV)
U238	351.92	352.07	-0.15	0.364	0.027	0.041	Pb-214 (U series), 351.9 keV
		368.51		0.109	0.037	0.037	Pu-239 (367.1 keV, 368.6 keV)
Pu239	375.05	375.15	-0.10	0.524	0.046	0.036	Pu-239 (375.1 keV)
		380.31		0.152	0.024	0.039	Pu-239 (380.2 keV)
		382.79		0.078	0.035	0.035	Pu-239 (382.8 keV)
		392.96		0.165	0.014	0.034	Pu-239 (392.5 keV)
		409.54		0.022	0.017	0.028	Ac-228 (Th series), 409.5 keV
		413.69		0.515	0.019	0.031	Pu-239 (413.7 keV)
		451.46		0.076	0.009	0.029	unknown; also occurs in DB591000
		463.02		0.059	0.008	0.028	Ac-228 (Th series), 463.0 keV
		510.78		0.615	0.037	0.034	annihilation radiation, 511.0 keV
Th232	583.19	583.02	0.17	0.424	0.012	0.024	Tl-208 (Th series), 583.2 keV
U238	609.31	609.14	0.17	0.486	0.016	0.023	Bi-214 (U series), 609.3 keV
		618.89		0.024	0.006	0.021	Am-241 (619.0 keV)
		652.28		0.018	0.006	0.019	below MDA, unknown, also observed in DB591000.
Cs137	661.66	662.18	-0.52	0.172	0.012	0.021	probably Am-241 (662.4 keV)
		721.69		0.098	0.007	0.019	Am-241 (722.0 keV)
		727.07		0.100	0.007	0.019	Bi-212 (Th series), 727.3 keV
		763.97		0.016	0.012	0.017	below MDA, may be

Table D-23. (continued).

Library ID	Library Energy (keV)	Calculated Energy (keV	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
							Tl-208 (Th series), 763.1 keV
U238p	766.36	767.96	-1.60	0.070	0.014	0.017	Bi-214 (U series) 768.3 keV
		772.10		0.023	0.012	0.017	Ac-228 (Th series), 772.3 keV
		785.31		0.013	0.012	0.019	below MDA; may be Pb-214 (U series), 785.9 keV; Bi-212 (Th series) 785.4 keV
Cs134	795.85	794.62	1.23	0.063	0.011	0.017	Ac-228 (Th series), 794.9 keV
		805.51		0.015	0.005	0.016	Bi-214 (U series), 806.2 keV
		860.26		0.063	0.006	0.016	Tl-208 (Th series), 860.6 keV
		893.11		0.010	0.005	0.015	below MDA, probably spurious
Th232	911.21	910.85	0.36	0.387	0.015	0.016	Ac-228 (Th series), 911.2 keV
		933.63		0.038	0.005	0.015	Bi-214 (U series), 934.1 keV
		949.09		0.011	0.005	0.014	1460.8 keV (K-40) escape peak (949.8 keV)
		964.36		0.068	0.008	0.016	Bi-214 (U series) 964.1 keV
		968.60		0.240	0.011	0.015	Ac-228 (Th series), 969.0 keV
U238p	1,001.03	1,000.73	0.30	0.057	0.007	0.015	Pa-234m (U series), 1001.0 keV
		1,050.13		0.011	0.005	0.013	below MDA, probably spurious
		1,078.00		0.010	0.004	0.014	Bi-212 (Th series) 1078.6 keV
		1,103.47		0.009	0.007	0.013	below MDA, probably spurious
		1,119.96		0.183	0.006	0.015	Bi-214 (U series), 1120.3 keV
		1,154.79		0.023	0.008	0.014	Bi-214 (U series), 1155.2 keV
		1,237.87		0.072	0.005	0.014	Bi-214 (U series), 1238.1 keV
Eu154	1,274.44	1,274.17	0.27	0.025	0.006	0.012	unknown; probably not Eu-154, no confirming peak at 723.3 keV or 123.1 keV
		1,281.03		0.011	0.006	0.012	Bi-214 (U series), 1281.0 keV
		1,315.64		0.006	0.004	0.010	below MDA, probably spurious
		1,377.64		0.050	0.005	0.010	Bi-214 (U series), 1377.7 keV
		1,401.52		0.017	0.003	0.010	Bi-214 (U series), 1401.5 keV
Eu152	1,408.01	1,407.89	0.12	0.030	0.004	0.010	Bi-214 (U series), 1408.0 keV
		1,451.33		0.011	0.006	0.009	unknown; also observed in DB511000 and DB521000
K-40	1,460.83	1,460.81	0.02	2.194	0.069	0.010	K-40, 1460.8 keV
		1,495.98		0.019	0.004	0.008	Ac-228 (Th series), 1495.9 keV
		1,502.11		0.010	0.003	0.008	Ac-228 (Th series), 1501.6 keV

Table D-23. (continued).

Library ID	Library Energy (keV)	Calculated Energy (keV	Energy Residual (keV)	Peak Intensity (c/s)	Intensity Uncert. (c/s)	MDA (c/s)	Analyst Comments
		1,509.37		0.031	0.004	0.008	Bi-214 (U series), 1509.2 keV
		1,581.85		0.009	0.004	0.008	Ac-228 (Th series), 1580.5 keV
		1,588.37		0.048	0.005	0.009	Ac-228 (Th series), 1588.2 keV
		1,592.80		0.045	0.005	0.008	2614.5 keV (Tl-208) double escape peak (1592.5 keV)
		1,620.97		0.032	0.004	0.008	Bi-212 (Th series), 1620.5 keV
		1,630.86		0.024	0.004	0.007	Ac-228 (Th series), 1630.6 keV
		1,638.45		0.008	0.004	0.007	Ac-228 (Th series), 1638.3 keV
		1,661.43		0.010	0.003	0.007	Bi-214 (U series), 1661.3 keV
		1,730.07		0.030	0.007	0.008	Bi-214 (U series), 1729.6 keV
U238	1,764.49	1,764.99	-0.50	0.200	0.010	0.008	Bi-214 (U series), 1764.5 keV
		1,809.33		0.011	0.003	0.007	unknown; also observed in DB531000
		1,848.05		0.025	0.003	0.007	Bi-214 (U series), 1847.4 keV
		2,103.78		0.078	0.006	0.007	2614.5 keV (Tl-208) escape peak (2103.5 keV)
		2,118.95		0.014	0.003	0.007	Bi-214 (U series), 2118.5 keV
		2,204.29		0.064	0.004	0.007	Bi-214 (U series), 2204.2 keV
		2,223.49		0.074	0.004	0.007	H neutron capture gamma ray
		2,447.66		0.021	0.003	0.006	Bi-214 (U series), 2447.9 keV
Th232	2,614.53	2,614.34	0.18	0.700	0.021	0.004	Tl-208 (Th series), 2614.5 keV
		2,753.39		0.003	0.001	0.003	indistinct with bad background fit, spurious
		2,774.03		0.015	0.012	0.006	indistinct with bad background fit, spurious

ATTACHMENT

INEEL Passive Gamma-Ray Spectrum DB501000.CHN

February 2, 2004

Site	SDA Area 5
Borehole	P6-PU-2
Depth	20.06 feet
Acquisition Date	January 15, 2004
Logging System	Gamma 4B (35-percent-efficient HPGe, 36TP21095A)
Counting Time	8 hours (28724.5 seconds, live time)
Data Analyst	C. J. Koizumi

The before-survey spectrum (DB501CAB.CHN) and post-survey spectrum (DB501CAA.CHN) were analyzed. Nothing indicative of system malfunctions was observed.

The before-survey spectrum was energy-calibrated, then that energy calibration was "imported" to the post-survey spectrum. The peaks in the post-survey spectrum were shifted in energy as indicated by the plot in Figure D-1.

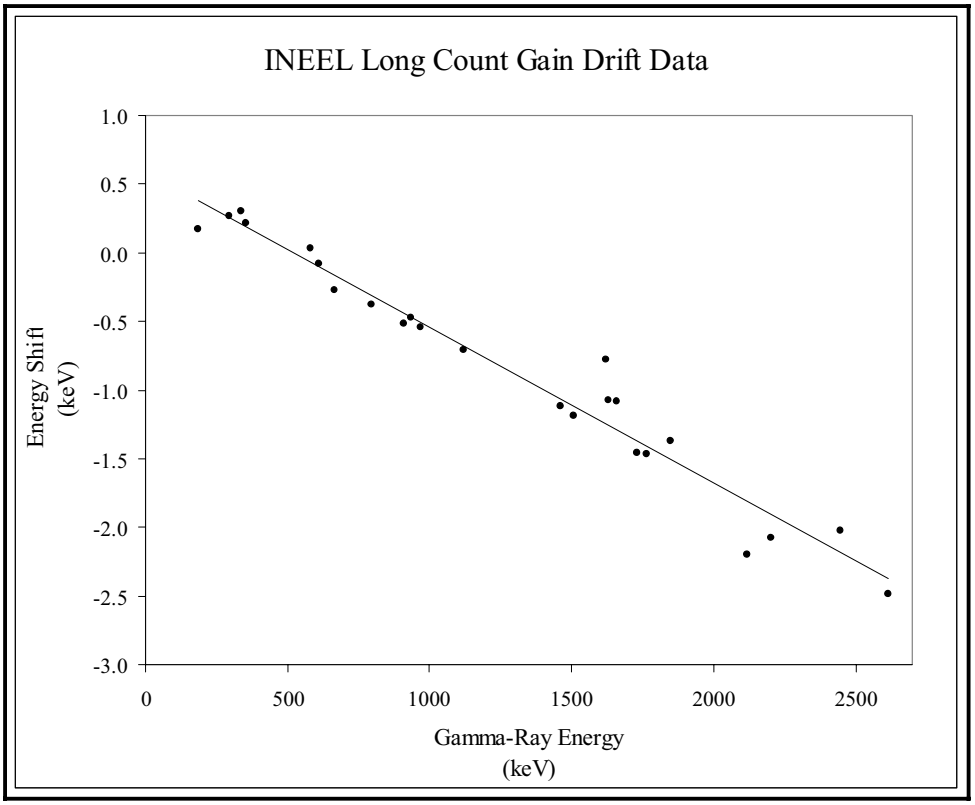

Figure D-1. Gain shift over the acquisition time.

The apparent energy shift was a function of gamma ray energy. The greatest shift of approximately -2.5 keV occurred for the peak associated with the 2614.5-keV gamma ray of Tl-208 (Th series). (The spectrum analysis program calculated the energy to be 2612.0 keV in the post-survey spectrum.) The gain drift should not be overlooked because drift broadens the spectral peak widths. This could cause counts due to a particular gamma ray to be tallied in a wide peak that could be erroneously resolved into two or more "multiplets" by the *Multifit* (Gaussian peak fitting) algorithm in the spectrum analysis software. The plot in Figure D-1 indicates the net gain shift and gives no information about the rate of gain drift over time.

The borehole spectrum DB501000.CHN was energy-calibrated, then analyzed by two methods. The important analysis settings common to both methods were as follows.

- ROI Properties
    - Background curve: third degree
    - Background end points: five on each side of the peak
- Peaksearch
    - Maximum error of 100 percent.

The *Identify* algorithm in the analysis program referenced a source identification data base (library) containing the most intense gamma rays for Am-241, Co-60, Cs-134, Cs-137, Eu-152, Eu-154, Np-237, Pu-239, Ru-106, Sb-125, Sb-126, and Tc-99. Using this library, the analysis program will identify these man-made sources whenever the concentrations are high enough to produce detectable gamma ray peaks.

The first analysis employed the *Peaksearch* and *Identify* algorithms in the analysis program, and yielded the data in Tables 1 and 2.

Table 1. Peaks identified by *Peaksearch* and *Identify.*

Source	Library Energy (keV)	Calculated Energy (keV)	Energy Residual (keV)	Peak FWHM (keV)	Peak Intensity (c/s)
U238	351.92	351.86	0.06	1.74	0.419 ± 0.029
Th232	583.19	583.22	-0.03	1.92	0.446 ± 0.017
U238	609.31	609.37	-0.06	2.05	0.553 ± 0.016
Cs134	795.85	794.99	0.86	2.32	0.053 ± 0.012
Th232	911.21	911.16	0.05	2.26	0.373 ± 0.014
U238p	1,001.03	1,000.84	0.19	2.98	0.019 ± 0.008
Eu152	1,408.01	1,407.91	0.10	2.46	0.033 ± 0.006
K-40	1,460.83	1,460.70	0.13	2.98	2.112 ± 0.019
U238	1,764.49	1,764.58	-0.09	3.19	0.220 ± 0.007
Th232	2,614.53	2,614.49	0.04	4.05	0.558 ± 0.009

Table 2. Peaks not identified by *Peaksearch* and *Identify*.

Peak Number	Calculated Energy (keV)	Peak Intensity (c/s)	MDA[a] (c/s)
1	238.59	0.629 ± 0.034	0.054
2	295.19	0.218 ± 0.032	0.052
3	338.34	0.148 ± 0.028	0.045
5	463.04	0.057 ± 0.017	0.027
6	510.80	0.319 ± 0.024	0.039
9	727.27	0.102 ± 0.013	0.021
10	768.31	0.061 ± 0.014	0.023
12	836.16	0.024 ± 0.011	0.018
13	860.54	0.061 ± 0.011	0.018
15	934.06	0.043 ± 0.011	0.018
16	968.86	0.315 ± 0.015	0.021
18	1,120.16	0.201 ± 0.010	0.015
19	1,155.13	0.035 ± 0.009	0.015
20	1,238.05	0.082 ± 0.012	0.019
21	1,377.45	0.061 ± 0.006	0.009
22	1,400.96	0.021 ± 0.005	0.008
25	1,496.05	0.012 ± 0.004	0.007
26	1,501.07	0.008 ± 0.004	0.006
27	1,509.11	0.029 ± 0.005	0.008
28	1,581.92	0.019 ± 0.004	0.005
29	1,588.43	0.094 ± 0.006	0.007
30	1,598.83	0.006 ± 0.003	0.005
31	1,620.64	0.024 ± 0.005	0.007
32	1,630.35	0.021 ± 0.004	0.006
33	1,660.99	0.018 ± 0.005	0.007
34	1,729.77	0.036 ± 0.004	0.006
36	1,847.69	0.029 ± 0.004	0.006
37	2,103.44	0.072 ± 0.005	0.006
38	2,118.11	0.014 ± 0.004	0.006
39	2,203.58	0.069 ± 0.005	0.006
40	2,447.35	0.021 ± 0.003	0.005

a. Minimum Detectable Activity

The second analysis employed the *Peaksearch, Multifit,* and *Identify* algorithms in the analysis program. *Multifit* was executed because of the possibility that peaks were significantly broadened by gain drift. With broad peaks, several analysis errors are possible. Several peaks due to gamma rays with similar energies can merge into a "multiplet," and one or more of the peaks in the multiplet can go undetected. It is also possible that signals due to monoenergetic gamma rays can produce a broad peak that the analysis program resolves as two or more peaks.

The second analysis yielded the data in Tables 3 and 4.

Table 3. Peaks identified by *Peaksearch*, *Multifit*, and *Identify*.

Source	Library Energy (keV)	Calculated Energy (keV)	Energy Residual (keV)	Peak FWHM (keV)	Flag	Peak Intensity (c/s)
U235	185.72	185.88	-0.16	2.14	?[a]	0.048 ± 0.032
U238	351.92	351.86	0.06	1.73		0.416 ± 0.023
Th232	583.19	583.22	-0.03	1.92		0.446 ± 0.017
U238	609.31	609.37	-0.06	2.05		0.553 ± 0.016
Cs134	795.85	795.02	0.83	2.19	M[b]	0.064 ± 0.008
Th232	911.21	911.16	0.05	2.28		0.390 ± 0.013
U238p	1,001.03	1,001.00	0.03	—		0.028 ± 0.007
Eu152	1,408.01	1,408.04	-0.03	2.83	m	0.029 ± 0.003
K-40	1,460.83	1,460.70	0.13	2.98		2.114 ± 0.018
U238	1,764.49	1,764.59	-0.10	3.20		0.222 ± 0.007
Th232	2,614.53	2,614.49	0.04	4.05		0.558 ± 0.009

a. The peak intensity was below the MDA.
b. The peak was a component in a multiplet.

Table 4. Peaks not identified by *Peaksearch*, *Multifit*, and *Identify*.

Peak Number	Calculated Energy (keV)	Flag	Peak Intensity (keV)	MDA (c/s)
1	127.26	?	0.042 ± 0.035	0.058
3	238.59		0.629 ± 0.034	0.054
4	270.52	?	0.039 ± 0.025	0.041
5	294.61		0.166 ± 14.89	0.035
6	338.34		0.135 ± 0.021	0.034
8	463.04		0.056 ± 0.015	0.025
9	510.80		0.295 ± 0.017	0.026
12	665.44	?	0.013 ± 0.010	0.017
13	727.27		0.103 ± 0.013	0.020
14	755.38		0.025 ± 0.010	0.016

Table 4. (continued).

Peak Number	Calculated Energy (keV)	Flag	Peak Intensity (keV)	MDA (c/s)
15	768.27		0.031 ± 0.010	0.017
16	785.62	m	0.019 ± 0.007	0.015
18	806.28	?	0.016 ± 0.010	0.016
19	830.98	m?	0.012 ± 0.006	0.014
20	836.00	m	0.022 ± 0.006	0.014
21	860.55		0.064 ± 0.009	0.015
23	934.09		0.042 ± 0.010	0.017
24	949.64		0.017 ± 0.008	0.014
25	964.65	m	0.074 ± 0.005	0.014
26	968.91	m	0.242 ± 0.007	0.014
27	980.89	?	0.009 ± 0.008	0.013
29	1,078.62	?	0.009 ± 0.007	0.011
30	1,120.16		0.201 ± 0.010	0.015
31	1,155.13		0.035 ± 0.009	0.015
32	1,208.27	?	0.008 ± 0.007	0.012
33	1,237.63		0.072 ± 0.008	0.013
34	1,281.04		0.012 ± 0.007	0.011
35	1,377.51	m	0.060 ± 0.004	0.010
36	1,385.35	m	0.011 ± 0.003	0.009
37	1,401.01	m	0.019 ± 0.003	0.009
40	1,495.94	m	0.011 ± 0.004	0.007
41	1,501.66	m?	0.005 ± 0.003	0.007
42	1,509.35	m	0.026 ± 0.004	0.007
43	1,554.93	?	0.005 ± 0.003	0.006
44	1,581.57	m	0.011 ± 0.004	0.006
45	1,588.14	m	0.048 ± 0.006	0.006
46	1,592.57	m	0.038 ± 0.005	0.007
47	1,620.82	m	0.022 ± 0.004	0.006
48	1,630.38	m	0.030 ± 0.005	0.006
49	1,660.97		0.014 ± 0.004	0.006
50	1,729.64		0.037 ± 0.004	0.006
52	1,793.53	?	-0.001 ± 0.012	0.004
53	1,838.33	m?	0.004 ± 0.002	0.005

Table 4. (continued).

Peak Number	Calculated Energy (keV)	Flag	Peak Intensity (keV)	MDA (c/s)
54	1,847.75	m	0.028 ± 0.003	0.005
55	1,872.52	m	0.005 ± 0.002	0.005
56	1,876.32	m?	0.004 ± 0.002	0.005
57	1,937.14	?	0.003 ± 0.003	0.004
58	2,103.43		0.070 ± 0.005	0.006
59	2,118.16		0.018 ± 0.003	0.005
60	2,203.58		0.069 ± 0.005	0.006
61	2,447.35		0.021 ± 0.003	0.005
63	2,805.18	?	0.0008 ± 0.0007	0.0010

The peaks in Table 3 correlate well to their counterparts in Table 1, and in general, no peaks were broad enough to be erroneously resolved as multiplets. Table 3 has an entry for a peak at 185.7 keV (composite peak for the 185.7-keV gamma ray of U-235 and the 186.1-keV gamma ray of Ra-226) that does not appear in Table 1. This peak was found as a result of the *Multifit* execution, but the intensity is less than the MDA.

Tables 2 and 4 indicate that when the *Multifit* algorithm was employed, the analysis program found 23 peaks more than were found without running *Multifit*. Table 2 has a peak at 1598.8 keV that is absent from Table 4.

All of the peaks that the analysis program attributed to man-made sources or unknown sources are listed in Table 5. These peaks were individually assessed. The results of the assessments are in the right side column of Table 5.

Table 5. Assessment of peaks not identified by analysis program.

Program ID	Calculated Energy (keV)	Flag	Peak Intensity (c/s)	MDA (c/s)	Analyst's IDs and Comments
	127.26	?	0.042 ± 0.035	0.058	intensity below MDA, probably spurious
	238.59		0.629 ± 0.034	0.054	Pb-212 (Th series), 238.6 keV
	270.52	?	0.039 ± 0.025	0.041	below MDA, but identified as Ac-228 (Th series), at 270.2 keV
	294.61		0.166 ± 14.9	0.035	Pb-214 (U series), 295.2 keV, large uncertainty
	338.34		0.135 ± 0.021	0.034	Ac-228 (Th series), 338.3 keV
	463.04		0.056 ± 0.015	0.025	Ac-228 (Th series), 463.0 keV
	510.80		0.295 ± 0.017	0.026	annihilation radiation (511.0 keV)
	665.44	?	0.013 ± 0.010	0.017	below MDA, but identified as Bi-214 (U series), 665.4 keV
	727.27		0.103 ± 0.013	0.020	Ac-228, 726.9 keV; Bi-212 (Th series), 727.3 keV
	755.38		0.025 ± 0.010	0.016	Ac-228 (Th series), 755.3 keV

Table 5. (continued).

Program ID	Calculated Energy (keV)	Flag	Peak Intensity (c/s)	MDA (c/s)	Analyst's IDs and Comments
	768.27		0.031 ± 0.010	0.017	Bi-214 (U series), 768.3 keV
	785.62	m	0.019 ± 0.007	0.015	Pb-214 (U series), 785.9 keV; Bi-212 (Th series) 785.4 keV
Cs134	795.02		0.064 ± 0.008	0.015	Ac-228 (Th series), 794.9 keV
	806.28	?	0.016 ± 0.010	0.016	below MDA, but identified as Bi-214 (U series), 806.2 keV
	830.98	m?	0.012 ± 0.006	0.014	below MDA, but identified asAc-228 (Th series), 830.5 keV
	836.00	m	0.022 ± 0.006	0.014	Ac-228 (Th series), 835.7 keV
	860.55		0.064 ± 0.009	0.015	Tl-208 (Th series), 860.6 keV
	934.09		0.042 ± 0.010	0.017	Bi-214 (U series), 934.1 keV
	949.64		0.017 ± 0.008	0.014	K-40 gamma escape peak (949.8 keV)
	964.65	m	0.074 ± 0.005	0.014	Bi-214 (U series) 964.1 keV
	968.91	m	0.242 ± 0.007	0.014	Ac-228 (Th series), 969.0 keV
	980.89	?	0.009 ± 0.008	0.013	below MDA, probably spurious
	1078.62	?	0.009 ± 0.007	0.011	below MDA, but identified as Bi-212 (Th series) 1078.6 keV
	1120.16		0.201 ± 0.010	0.015	Bi-214 (U series), 1120.3 keV
	1155.13		0.035 ± 0.009	0.015	Bi-214 (U series), 1155.2 keV
	1208.27	?	0.008 ± 0.007	0.012	below MDA, but identified as Bi-214 (U series), 1207.7 keV
	1237.63		0.072 ± 0.008	0.013	Bi-214 (U series), 1238.1 keV
	1281.04		0.012 ± 0.007	0.011	Bi-214 (U series), 1281.0 keV
	1377.51	m	0.060 ± 0.004	0.010	Bi-214 (U series), 1377.7 keV
	1385.35	m	0.011 ± 0.003	0.009	Bi-214 (U series), 1385.3 keV
	1401.01	m	0.019 ± 0.003	0.009	Bi-214 (U series), 1401.5 keV
Eu152	1408.04	m	0.029 ± 0.003	0.009	Bi-214 (U series), 1408.0 keV
	1495.94	m	0.011 ± 0.004	0.007	Ac-228 (Th series), 1495.9 keV
	1501.66	m?	0.005 ± 0.003	0.007	below MDA, but identified as Ac-228 (Th series), 1501.6 keV
	1509.35	m	0.026 ± 0.004	0.007	Bi-214 (U series), 1509.2 keV
	1554.93	?	0.005 ± 0.003	0.006	below MDA, probably spurious
	1581.57	m	0.011 ± 0.004	0.006	Ac-228 (Th series), 1580.5 keV
	1588.14	m	0.048 ± 0.006	0.006	Ac-228 (Th series), 1588.2 keV
	1592.57	m	0.038 ± 0.005	0.007	Tl-208 (Th series) pair at 1592.5 keV
	1598.83		0.006 ± 0.003	0.005	Bi-214 (U series), 1599.3 keV
	1620.82	m	0.022 ± 0.004	0.006	Bi-212 (Th series), 1620.5 keV

Table 5. (continued).

Program ID	Calculated Energy (keV)	Flag	Peak Intensity (c/s)	MDA (c/s)	Analyst's IDs and Comments
	1630.38	m	0.030 ± 0.005	0.006	Ac-228 (Th series), 1630.6 keV
	1660.97		0.014 ± 0.004	0.006	Bi-214 (U series), 1661.3 keV
	1729.64		0.037 ± 0.004	0.006	Bi-214 (U series), 1729.6 keV
	1793.53	?	-0.001 ± 0.012	0.004	below MDA, negative intensity, most likely spurious
	1838.33	m?	0.004 ± 0.002	0.005	Bi-214 (U series), 1838.4 keV
	1847.75	m	0.028 ± 0.003	0.005	Bi-214 (U series), 1847.4 keV
	1872.52	m	0.005 ± 0.002	0.005	Bi-214 (U series), 1873.2 keV
	1876.32	m?	0.004 ± 0.002	0.005	below MDA, probably spurious
	1937.14	?	0.003 ± 0.003	0.004	below MDA, but 1936.6 keV occurs in SBU cal spectra
	2103.43		0.070 ± 0.005	0.006	Tl-208 (Th series) pair at 2103.5 keV
	2118.16		0.018 ± 0.003	0.005	Bi-214 (U series), 2118.6 keV
	2203.58		0.069 ± 0.005	0.006	Bi-214 (U series), 2204.2 keV
	2447.35		0.021 ± 0.003	0.005	Bi-214 (U series), 2447.9 keV
	2805.18	?	0.0008 ± 0.0007	0.0010	below MDA, probably spurious

The Cs-134 identification is discounted because there is no evidence of a confirming peak corresponding to the 604.7-keV gamma ray of Cs-134. The 795-keV gamma ray is attributed to naturally occurring Ac-228 (794.9 keV) instead of Cs-134 (795.8 keV).

The Eu-152 identification is discounted because there is no evidence of confirming peaks corresponding to the Eu-152 gamma rays with energies 121.8 keV and 1112.1 keV. Thus, the 1408-keV gamma ray is attributed to naturally occurring Bi-214 (1408.0 keV), and likewise, the 965-keV gamma ray is attributed to Bi-214 (964.1 keV) and not Eu-152 (964.1 keV).

In summary, all of the spectral peaks are associated with naturally occurring potassium, uranium, and thorium. This spectrum shows no evidence of gamma rays originating in Am-241, Co-60, Cs-134, Cs-137, Eu-152, Eu-154, Np-237, Pu-239, Ru-106, Sb-125, Sb-126, or Tc-99.

Calculated natural background concentrations of potassium, uranium, and thorium are presented in Table 6. The peak intensities calculated with *Multifit* were used.

Table 6. Potassium, uranium, and thorium concentrations.

Source	Gamma Ray (keV)	Concentration (pCi/g)
Potassium (K-40)	1,460.8	16.7 ± 0.1
Uranium (Bi-214	609.3	1.14 ± 0.03
Thorium (TI-208)	2,614.5	1.25 ± 0.02

INEEL Passive Gamma-Ray Spectrum DB501000.CHN

February 2, 2004

Site	SDA Area 5
Borehole	P6-PU-2
Depth	20.06 feet
Acquisition Date	January 15, 2004
Logging System	Gamma 4B (35-percent-efficient HPGe, 36TP21095A)
Counting Time	8 hours (28724.5 seconds, live time)
Data Analyst	C. J. Koizumi

The before-survey spectrum (DB501CAB.CHN) and post-survey spectrum (DB501CAA.CHN) were analyzed. Nothing indicative of system malfunctions was observed.

The before-survey spectrum was energy-calibrated, then that energy calibration was "imported" to the post-survey spectrum. The peaks in the post-survey spectrum were shifted in energy as indicated by the plot in Figure D-2.

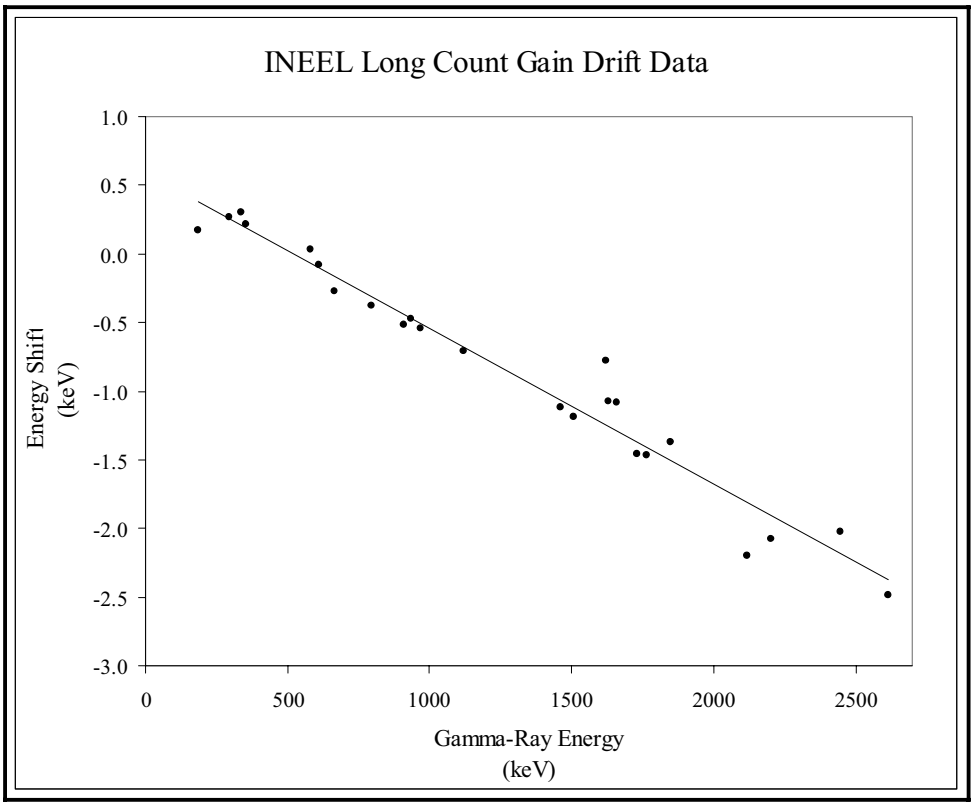

Figure D-2. Gain shift over the acquisition time.

The apparent energy shift was a function of gamma ray energy. The greatest shift of approximately -2.5 keV occurred for the peak associated with the 2614.5-keV gamma ray of Tl-208 (Th series). (The

spectrum analysis program calculated the energy to be 2612.0 keV in the post-survey spectrum.) The gain drift should not be overlooked because drift broadens the spectral peak widths. This could cause counts due to a particular gamma ray to be tallied in a wide peak that could be erroneously resolved into two or more "multiplets" by the *Multifit* (Gaussian peak fitting) algorithm in the spectrum analysis software. The plot in Figure D-2 indicates the net gain shift and gives no information about the rate of gain drift over time.

The borehole spectrum DB501000.CHN was energy-calibrated, then analyzed by two methods. The important analysis settings common to both methods were as follows.

- ROI Properties
    - Background curve: third degree
    - Background end points: five on each side of the peak
- Peaksearch
    - Maximum error of 100 percent.

The *Identify* algorithm in the analysis program referenced a source identification data base (library) containing the most intense gamma rays for Am-241, Co-60, Cs-134, Cs-137, Eu-152, Eu-154, Np-237, Pu-239, Ru-106, Sb-125, Sb-126, and Tc-99. Using this library, the analysis program will identify these man-made sources whenever the concentrations are high enough to produce detectable gamma ray peaks.

The first analysis employed the *Peaksearch* and *Identify* algorithms in the analysis program, and yielded the data in Tables 1 and 2.

Table 1. Peaks identified by *Peaksearch* and *Identify*.

Source	Library Energy (keV)	Calculated Energy (keV)	Energy Residual (keV)	Peak FWHM (keV)	Peak Intensity (c/s)
U238	351.92	351.86	0.06	1.74	0.419 ± 0.029
Th232	583.19	583.22	-0.03	1.92	0.446 ± 0.017
U238	609.31	609.37	-0.06	2.05	0.553 ± 0.016
Cs134	795.85	794.99	0.86	2.32	0.053 ± 0.012
Th232	911.21	911.16	0.05	2.26	0.373 ± 0.014
U238p	1,001.03	1,000.84	0.19	2.98	0.019 ± 0.008
Eu152	1,408.01	1,407.91	0.10	2.46	0.033 ± 0.006
K-40	1,460.83	1,460.70	0.13	2.98	2.112 ± 0.019
U238	1,764.49	1,764.58	-0.09	3.19	0.220 ± 0.007
Th232	2,614.53	2,614.49	0.04	4.05	0.558 ± 0.009

Table 2. Peaks not identified by *Peaksearch* and *Identify*.

Peak Number	Calculated Energy (keV)	Peak Intensity (c/s)	MDA[a] (c/s)
1	238.59	0.629 ± 0.034	0.054
2	295.19	0.218 ± 0.032	0.052
3	338.34	0.148 ± 0.028	0.045
5	463.04	0.057 ± 0.017	0.027
6	510.80	0.319 ± 0.024	0.039
9	727.27	0.102 ± 0.013	0.021
10	768.31	0.061 ± 0.014	0.023
12	836.16	0.024 ± 0.011	0.018
13	860.54	0.061 ± 0.011	0.018
15	934.06	0.043 ± 0.011	0.018
16	968.86	0.315 ± 0.015	0.021
18	1,120.16	0.201 ± 0.010	0.015
19	1,155.13	0.035 ± 0.009	0.015
20	1,238.05	0.082 ± 0.012	0.019
21	1,377.45	0.061 ± 0.006	0.009
22	1,400.96	0.021 ± 0.005	0.008
25	1,496.05	0.012 ± 0.004	0.007
26	1,501.07	0.008 ± 0.004	0.006
27	1,509.11	0.029 ± 0.005	0.008
28	1,581.92	0.019 ± 0.004	0.005
29	1,588.43	0.094 ± 0.006	0.007
30	1,598.83	0.006 ± 0.003	0.005
31	1,620.64	0.024 ± 0.005	0.007
32	1,630.35	0.021 ± 0.004	0.006
33	1,660.99	0.018 ± 0.005	0.007
34	1,729.77	0.036 ± 0.004	0.006
36	1,847.69	0.029 ± 0.004	0.006
37	2,103.44	0.072 ± 0.005	0.006
38	2,118.11	0.014 ± 0.004	0.006
39	2,203.58	0.069 ± 0.005	0.006
40	2,447.35	0.021 ± 0.003	0.005

a. Minimum detectable activity

The second analysis employed the *Peaksearch, Multifit,* and *Identify* algorithms in the analysis program. *Multifit* was executed because of the possibility that peaks were significantly broadened by gain drift. With broad peaks, several analysis errors are possible. Several peaks due to gamma rays with similar energies can merge into a "multiplet," and one or more of the peaks in the multiplet can go undetected. It is also possible that signals due to monoenergetic gamma rays can produce a broad peak that the analysis program resolves as two or more peaks.

The second analysis yielded the data in Tables 3 and 4.

Table 3. Peaks identified by *Peaksearch, Multifit,* and *Identify.*

Source	Library Energy (keV)	Calculated Energy (keV)	Energy Residual (keV)	Peak FWHM (keV)	Flag	Peak Intensity (c/s)
U235	185.72	185.88	-0.16	2.14	?[a]	0.048 ± 0.032
U238	351.92	351.86	0.06	1.73		0.416 ± 0.023
Th232	583.19	583.22	-0.03	1.92		0.446 ± 0.017
U238	609.31	609.37	-0.06	2.05		0.553 ± 0.016
Cs134	795.85	795.02	0.83	2.19	M[b]	0.064 ± 0.008
Th232	911.21	911.16	0.05	2.28		0.390 ± 0.013
U238p	1,001.03	1,001.00	0.03	—		0.028 ± 0.007
Eu152	1,408.01	1,408.04	-0.03	2.83	m	0.029 ± 0.003
K-40	1,460.83	1,460.70	0.13	2.98		2.114 ± 0.018
U238	1,764.49	1,764.59	-0.10	3.20		0.222 ± 0.007
Th232	2,614.53	2,614.49	0.04	4.05		0.558 ± 0.009

a. The peak intensity was below the MDA.
b. The peak was a component in a multiplet.

Table 4. Peaks not identified by *Peaksearch*, *Multifit*, and *Identify*.

Peak Number	Calculated Energy (keV)	Flag	Peak Intensity (keV)	MDA (c/s)
1	127.26	?	0.042 ± 0.035	0.058
3	238.59		0.629 ± 0.034	0.054
4	270.52	?	0.039 ± 0.025	0.041
5	294.61		0.166 ± 14.89	0.035
6	338.34		0.135 ± 0.021	0.034
8	463.04		0.056 ± 0.015	0.025
9	510.80		0.295 ± 0.017	0.026
12	665.44	?	0.013 ± 0.010	0.017
13	727.27		0.103 ± 0.013	0.020

Table 4. (continued).

Peak Number	Calculated Energy (keV)	Flag	Peak Intensity (keV)	MDA (c/s)
14	755.38		0.025 ± 0.010	0.016
15	768.27		0.031 ± 0.010	0.017
16	785.62	m	0.019 ± 0.007	0.015
18	806.28	?	0.016 ± 0.010	0.016
19	830.98	m?	0.012 ± 0.006	0.014
20	836.00	m	0.022 ± 0.006	0.014
21	860.55		0.064 ± 0.009	0.015
23	934.09		0.042 ± 0.010	0.017
24	949.64		0.017 ± 0.008	0.014
25	964.65	m	0.074 ± 0.005	0.014
26	968.91	m	0.242 ± 0.007	0.014
27	980.89	?	0.009 ± 0.008	0.013
29	1,078.62	?	0.009 ± 0.007	0.011
30	1,120.16		0.201 ± 0.010	0.015
31	1,155.13		0.035 ± 0.009	0.015
32	1,208.27	?	0.008 ± 0.007	0.012
33	1,237.63		0.072 ± 0.008	0.013
34	1,281.04		0.012 ± 0.007	0.011
35	1,377.51	m	0.060 ± 0.004	0.010
36	1,385.35	m	0.011 ± 0.003	0.009
37	1,401.01	m	0.019 ± 0.003	0.009
40	1,495.94	m	0.011 ± 0.004	0.007
41	1,501.66	m?	0.005 ± 0.003	0.007
42	1,509.35	m	0.026 ± 0.004	0.007
43	1,554.93	?	0.005 ± 0.003	0.006
44	1,581.57	m	0.011 ± 0.004	0.006
45	1,588.14	m	0.048 ± 0.006	0.006
46	1,592.57	m	0.038 ± 0.005	0.007
47	1,620.82	m	0.022 ± 0.004	0.006
48	1,630.38	m	0.030 ± 0.005	0.006
49	1,660.97		0.014 ± 0.004	0.006
50	1,729.64		0.037 ± 0.004	0.006
52	1,793.53	?	-0.001 ± 0.012	0.004

Table 4. (continued).

Peak Number	Calculated Energy (keV)	Flag	Peak Intensity (keV)	MDA (c/s)
53	1,838.33	m?	0.004 ± 0.002	0.005
54	1,847.75	m	0.028 ± 0.003	0.005
55	1,872.52	m	0.005 ± 0.002	0.005
56	1,876.32	m?	0.004 ± 0.002	0.005
57	1,937.14	?	0.003 ± 0.003	0.004
58	2,103.43		0.070 ± 0.005	0.006
59	2,118.16		0.018 ± 0.003	0.005
60	2,203.58		0.069 ± 0.005	0.006
61	2,447.35		0.021 ± 0.003	0.005
63	2,805.18	?	0.0008 ± 0.0007	0.0010

The peaks in Table 3 correlate well to their counterparts in Table 1, and in general, no peaks were broad enough to be erroneously resolved as multiplets. Table 3 has an entry for a peak at 185.7 keV (composite peak for the 185.7-keV gamma ray of U-235 and the 186.1-keV gamma ray of Ra-226) that does not appear in Table 1. This peak was found as a result of the *Multifit* execution, but the intensity is less than the MDA.

Tables 2 and 4 indicate that when the *Multifit* algorithm was employed, the analysis program found 23 peaks more than were found without running *Multifit*. Table 2 has a peak at 1598.8 keV that is absent from Table 4.

All of the peaks that the analysis program attributed to man-made sources or unknown sources are listed in Table 5. These peaks were individually assessed. The results of the assessments are in the right side column of Table 5.

Table 5. Assessment of peaks not identified by analysis program.

Program ID	Calculated Energy (keV)	Flag	Peak Intensity (c/s)	MDA (c/s)	Analyst's IDs and Comments
	127.26	?	0.042 ± 0.035	0.058	intensity below MDA, probably spurious
	238.59		0.629 ± 0.034	0.054	Pb-212 (Th series), 238.6 keV
	270.52	?	0.039 ± 0.025	0.041	below MDA, but identified as Ac-228 (Th series), at 270.2 keV
	294.61		0.166 ± 14.9	0.035	Pb-214 (U series), 295.2 keV, large uncertainty
	338.34		0.135 ± 0.021	0.034	Ac-228 (Th series), 338.3 keV
	463.04		0.056 ± 0.015	0.025	Ac-228 (Th series), 463.0 keV
	510.80		0.295 ± 0.017	0.026	annihilation radiation (511.0 keV)
	665.44	?	0.013 ± 0.010	0.017	below MDA, but identified as Bi-214 (U series), 665.4 keV
	727.27		0.103 ± 0.013	0.020	Ac-228, 726.9 keV; Bi-212 (Th series), 727.3 keV
	755.38		0.025 ± 0.010	0.016	Ac-228 (Th series), 755.3 keV
	768.27		0.031 ± 0.010	0.017	Bi-214 (U series), 768.3 keV
	785.62	m	0.019 ± 0.007	0.015	Pb-214 (U series), 785.9 keV; Bi-212 (Th series) 785.4 keV

Table 5. (continued).

Program ID	Calculated Energy (keV)	Flag	Peak Intensity (c/s)	MDA (c/s)	Analyst's IDs and Comments
Cs134	795.02		0.064 ± 0.008	0.015	Ac-228 (Th series), 794.9 keV
	806.28	?	0.016 ± 0.010	0.016	below MDA, but identified as Bi-214 (U series), 806.2 keV
	830.98	m?	0.012 ± 0.006	0.014	below MDA, but identified asAc-228 (Th series), 830.5 keV
	836.00	m	0.022 ± 0.006	0.014	Ac-228 (Th series), 835.7 keV
	860.55		0.064 ± 0.009	0.015	Tl-208 (Th series), 860.6 keV
	934.09		0.042 ± 0.010	0.017	Bi-214 (U series), 934.1 keV
	949.64		0.017 ± 0.008	0.014	K-40 gamma escape peak (949.8 keV)
	964.65	m	0.074 ± 0.005	0.014	Bi-214 (U series) 964.1 keV
	968.91	m	0.242 ± 0.007	0.014	Ac-228 (Th series), 969.0 keV
	980.89	?	0.009 ± 0.008	0.013	below MDA, probably spurious
	1078.62	?	0.009 ± 0.007	0.011	below MDA, but identified as Bi-212 (Th series) 1078.6 keV
	1120.16		0.201 ± 0.010	0.015	Bi-214 (U series), 1120.3 keV
	1155.13		0.035 ± 0.009	0.015	Bi-214 (U series), 1155.2 keV
	1208.27	?	0.008 ± 0.007	0.012	below MDA, but identified as Bi-214 (U series), 1207.7 keV
	1237.63		0.072 ± 0.008	0.013	Bi-214 (U series), 1238.1 keV
	1281.04		0.012 ± 0.007	0.011	Bi-214 (U series), 1281.0 keV
	1377.51	m	0.060 ± 0.004	0.010	Bi-214 (U series), 1377.7 keV
	1385.35	m	0.011 ± 0.003	0.009	Bi-214 (U series), 1385.3 keV
	1401.01	m	0.019 ± 0.003	0.009	Bi-214 (U series), 1401.5 keV
Eu152	1408.04	m	0.029 ± 0.003	0.009	Bi-214 (U series), 1408.0 keV
	1495.94	m	0.011 ± 0.004	0.007	Ac-228 (Th series), 1495.9 keV
	1501.66	m?	0.005 ± 0.003	0.007	below MDA, but identified as Ac-228 (Th series), 1501.6 keV
	1509.35	m	0.026 ± 0.004	0.007	Bi-214 (U series), 1509.2 keV
	1554.93	?	0.005 ± 0.003	0.006	below MDA, probably spurious
	1581.57	m	0.011 ± 0.004	0.006	Ac-228 (Th series), 1580.5 keV
	1588.14	m	0.048 ± 0.006	0.006	Ac-228 (Th series), 1588.2 keV
	1592.57	m	0.038 ± 0.005	0.007	Tl-208 (Th series) pair at 1592.5 keV
	1598.83		0.006 ± 0.003	0.005	Bi-214 (U series), 1599.3 keV
	1620.82	m	0.022 ± 0.004	0.006	Bi-212 (Th series), 1620.5 keV
	1630.38	m	0.030 ± 0.005	0.006	Ac-228 (Th series), 1630.6 keV
	1660.97		0.014 ± 0.004	0.006	Bi-214 (U series), 1661.3 keV
	1729.64		0.037 ± 0.004	0.006	Bi-214 (U series), 1729.6 keV
	1793.53	?	-0.001 ± 0.012	0.004	below MDA, negative intensity, most likely spurious
	1838.33	m?	0.004 ± 0.002	0.005	Bi-214 (U series), 1838.4 keV
	1847.75	m	0.028 ± 0.003	0.005	Bi-214 (U series), 1847.4 keV
	1872.52	m	0.005 ± 0.002	0.005	Bi-214 (U series), 1873.2 keV
	1876.32	m?	0.004 ± 0.002	0.005	below MDA, probably spurious
	1937.14	?	0.003 ± 0.003	0.004	below MDA, but 1936.6 keV occurs in SBU cal spectra
	2103.43		0.070 ± 0.005	0.006	Tl-208 (Th series) pair at 2103.5 keV
	2118.16		0.018 ± 0.003	0.005	Bi-214 (U series), 2118.6 keV

Table 5. (continued).

Program ID	Calculated Energy (keV)	Flag	Peak Intensity (c/s)	MDA (c/s)	Analyst's IDs and Comments
	2203.58		0.069 ± 0.005	0.006	Bi-214 (U series), 2204.2 keV
	2447.35		0.021 ± 0.003	0.005	Bi-214 (U series), 2447.9 keV
	2805.18	?	0.0008 ± 0.0007	0.0010	below MDA, probably spurious

The Cs-134 identification is discounted because there is no evidence of a confirming peak corresponding to the 604.7-keV gamma ray of Cs-134. The 795-keV gamma ray is attributed to naturally occurring Ac-228 (794.9 keV) instead of Cs-134 (795.8 keV).

The Eu-152 identification is discounted because there is no evidence of confirming peaks corresponding to the Eu-152 gamma rays with energies 121.8 keV and 1112.1 keV. Thus, the 1408-keV gamma ray is attributed to naturally occurring Bi-214 (1408.0 keV), and likewise, the 965-keV gamma ray is attributed to Bi-214 (964.1 keV) and not Eu-152 (964.1 keV).

In summary, all of the spectral peaks are associated with naturally occurring potassium, uranium, and thorium. This spectrum shows no evidence of gamma rays originating in Am-241, Co-60, Cs-134, Cs-137, Eu-152, Eu-154, Np-237, Pu-239, Ru-106, Sb-125, Sb-126, or Tc-99.

Calculated natural background concentrations of potassium, uranium, and thorium are presented in Table 6. The peak intensities calculated with *Multifit* were used.

Table 6. Potassium, uranium, and thorium concentrations.

Source	Gamma Ray (keV)	Concentration (pCi/g)
Potassium (K-40)	1460.8	16.7 ± 0.1
Uranium (Bi-214)	609.3	1.14 ± 0.03
Thorium (Tl-208)	2614.5	1.25 ± 0.02

Appendix E

Moisture Sampling Data

Appendix E

Moisture Sampling Data

This appendix provides additional information concerning the soil moisture-sampling program at the Subsurface Disposal Area at the Idaho National Laboratory Radioactive Waste Management Complex including scanned images of the following:

- Two interoffice correspondence memoranda
- Field Team Leader's Daily Logbook entry form
- Soil moisure results
- Chain of custody form
- RWMC Operations-related task form.

Idaho National Engineering and Environmental Laboratory

INTEROFFICE MEMORANDUM

Date: September 4, 2003

To: J. L. Casper MS 4206 6-2682

From: T. J. Meyer TJM MS 3920 6-0730

Subject: SOIL SAMPLING FOR NUCLEAR LOGGING SOIL MOISTURE VERIFICATION

Recent soil moisture logging results from newly installed Type A probes indicate anomalous high values in the Pit 5 soil cover at depths of 2-3 feet. This letter directing soil sampling documents the objectives of a limited sampling effort to verify the soil moisture logging data.

Soil samples will be collected and analyzed for soil moisture content on a gravimetric basis. Soil samples will be collected adjacent to three newly installed Type A probes representing low, medium and high moisture contents as indicated by the moisture logging results. The three probes are HAL-1, UD-1 and UEU-4, which represent low, medium and high moisture contents, respectively. Soil samples should be collected as close as reasonably possible on the southwest side of each probe at approximate depths of 1 foot, 2 feet and 2.5-3 feet. The final soil sample depth is nonspecific, understanding that restrictions on the allowable depth of penetration in the SDA overburden may determine this depth.

Please record the sampling activities in a field logbook, noting the date, time, location, depth, personnel, weather conditions and soil description and the equipment used. Prepare a Sampling and Analysis Plan Table that lists the samples to be collected and the analyses required. Samples will be analyzed by Craig Bean at the INEEL Materials Testing Laboratory at CFA 602. Maintain the chain of custody for this sampling and have the samples analyzed using ASTM D2216-98, "Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass."

TJM:mp

cc: D. R. Myers, MS 3920 DRM
F. L. Webber, MS 3920
OU 7-13/14 Project File
T. J. Meyer Letter File (TJM-01-03)

Uniform File Code: 6102
Disposition Authority: ENV1-h-1
Retention Schedule: Cutoff at submission of the final financial status report for the site, or after resolution of all issues, whichever is later. Destroy 10 years after cutoff with written approval from the EPA award official.

NOTE: Original disposition authority, retention schedule, and Uniform Filing Code applied by the sender may not be appropriate for all recipients. Make adjustments as needed.

Idaho National Engineering and Environmental Laboratory

INTEROFFICE MEMORANDUM

Date: September 15, 2003

To:	T. J. Meyer	MS 3920	526-0730
From:	Carol Strong	MS 4206	526-8820

Subject: SOIL SAMPLING FOR NUCLEAR LOGGING SOIL MOISTURE VERIFICATION

Soil samples were collected on September 10, 2003 and analyzed for soil moisture content under the direction of your memo dated September 4, 2003.

These samples were taken approximately 6 inches southwest of Type A probe locations HAL-1, UD-1 and UEU-4 in the RWMC SDA. These locations have exhibited low, medium and high moisture contents, respectively, from recent soil moisture logging results. This sampling effort was done to verify the soil moisture logging data. Three depths were sampled at each location: approximately 1, 2 and 3 feet.

The sampling activities were conducted under an RWMC Operations Related Task (ORT) # 03-09 and JSA-047. Attachment 4 is a copy of the RWMC ORT 03-09. Samples were delivered to Craig Bean at the INEEL Materials Testing Laboratory at CFA 602 for moisture analysis using standard ASTM D2216-98. The analysis results were forwarded to Michele Johnson at TSB. Attachment 2 identifies the moisture results obtained from the testing laboratory at CFA.

Equipment used to sample was a steel hand auger with a 4-foot T-bar handle. The auger tip holding the soil was approximately 6 inches long and 3 inches in diameter. A 1-gallon plastic zip-lock bag was used to collect and transport each sample to the lab. The Sample and Analysis Management (SAM) provided labels and a Sample and Analysis Plan Table. Attachment 3 is a copy of the Chain of Custody #19399 which was filled out and accompanied the samples to the lab.

There were light rain showers and sprinkles passing over the SDA all day. Sampling was postponed until approximately 14:30 at which time the rain diminished to spitting. A 15-foot square tarp was used to cover the samplers and sample locations. All equipment was dry, and the ground was brushed off down to a dry surface. Attachment 1 includes the FTL Logbook notes describing the sampling activities, soil descriptions and sample disposition.

If you have any additional questions, please call me at 526-8820.

Carol Strong C J Strong

Attachments

cc: J. L. Casper
R. L. Jones
D. R. Myers
F. L. Webber
C. Strong Letter File
OU 7-13/14 Project File

Uniform File Code: 6102
Disposition Authority: ENV1-h-1
Retention Schedule: Cutoff at submission of the final financial status report for the site, or after resolution of all issues, whichever is later. Destroy 10 years after cutoff with written approval from the EPA award official.

NOTE: Original disposition authority, retention schedule, and Uniform Filing Code applied by the sender may not be appropriate for all recipients. Make adjustments as needed.

ATTACHMENT 1
FTL LOGBOOK ENTRY

FIELD TEAM LEADER'S DAILY LOGBOOK

10 Sept 2003. Today we are going to take soil samples and have the materials lab at CFA test them for moisture. In attendance is FTL Carol Strong, FTM Lance Hicks and Don Jenkinson, and RCT Mike Waters. A pre-job briefing was conducted at 09:25 and it included a discussion and review of the RWMC Operations Related Task #03-09 which was approved by Al Millhouse and recorded at the shift desk. Training was current. Equipment used to get the samples was a steel 4' long auger for hand augering. The augers tip was 3" diameter and ~5-6" long. 1 Gal plastic bags were used to contain and transport the samples with labels supplied by the SAM attached to the bags. The bags were zip-lorded shut. The weather was very cloudy, very cool, and the entire day had light rain showers and sprinkles passing over. We finally decided to sample after 14:00 when the rain deminished to spitting. We used a 15' x 15' tarp to hold our the sample location just to be sure nothing got wet. Moist soil/gravel on the surface was brushed aside

FTL: Carol Strong DA: Sabina Hardy

to give us a dry surface to start the hand auger. We tried to augur the holes as best as we could on the SW side and ~6" away from the existing Type A probe locations. Location HEH-4 which was located in a roadway had about 10" of gravel that we had to get through. The soil and gravel mixture caved in a couple of times, making it difficult to get a good 12" representative sample but we did our best. Sampling as follows: cs 9-10-03

Location	Time	FT. Depth	Soil Description
HAL-1-LOW	15:33	~1.0	• Light beige/brown, very fine. Location higher on edge of mound. cs 9/10/03
HAC-1-LOW	15:38	~2.0	
HAC-1-LOW	15:43	~3.0	
4D-1-MED	15:07	~1.0	• Fine to medium grained w/ some gravel (edge of road) soil somewhat moist, darker beige.
4D-1-MED	15:12	~2.0	
4D-1-MED	15:19	~3.0	
4EH-4-HIGH	14:48	~1.0	• moist & darker. Gravels mixed into top foot due to location in a graveled road.
4EH-4-HIGH	14:53	~2.0	
4EH-4-HIGH	14:57	~3.0	

The soil was very compacted & clods, but broke apart easily once in the bags. Samples were recorded on COC #19399 and delivered to Craig Bean @ the CFA Materials Testing Lab for soil analysis.

FTL: Carrie Strong QA: Sabra Hawley

21

FIELD TEAM LEADER'S DAILY LOGBOOK

(Continued) The results from the soil moisture will be sent directly to Michele Johnson @ TSB and it will be added to the database. cs 9/10/13

cs 9/10/13

FTL: Carol Strong

QA: Sabine Hardy

ATTACHMENT 2
SOIL MOISTURE RESULTS

Carol Strong, 2WMC SOIL MOISTURES INEEL Materials Lab

Project: Soil Sampling For Nuclear Logging / Soil Moisture Verification Date: 9-11-03

Sample ID #: SMV 00601 M7 - Lab Log 041 UEU-1 19.2% % Moisture = 19.5%

Weight of sample + container (wet):	678.10	Wt. of Moist:	62.04
Weight of sample + container (dry):	616.06		
Weight of container (tare wt) :	297.25	Wt. of soil:	318.81

Sample ID#: SMV 00701 M7 Lab Log 042 UEU-1 32.2% % Moisture = 22.2%

Weight of sample + container (wet):	646.09	Wt. of Moist:	66.26
Weight of sample + container (dry):	579.83		
Weight of container (tare wt) :	281.52	Wt. of soil:	298.31

Sample ID#: SMV 00801 M7 - Lab Log 043 UEU-1 32% % Moisture = 24.5%

Weight of sample + container (wet):	789.60	Wt. of Moist:	97.43
Weight of sample + container (dry):	692.17		
Weight of container (tare wt.) :	295.16	wt. of soil:	397.01

Sample ID#: SMV 00301 M7 - Lab Log 044 UD-1 16.2% % Moisture = 13.4%

Weight of sample + container (wet):	831.65	Wt. of Moist:	63.26
Weight of sample + container (dry):	768.39		
Weight of container (tare wt.) :	295.78	wt. of soil:	472.61

Sample ID#: SMV 00401 M7 - Lab Log 045 UD-1 22.2% % Moisture = 16.6%

Weight of sample + container (wet):	659.83	Wt of Moist:	52.54
Weight of sample + container (dry):	607.29		
Weight of container (tare wt.) :	291.07	wt. of soil:	316.22

Sample ID#: SMV 00501 M7 - Lab Log 046 UD-1 22.3% % Moisture = 19.3%

Weight of sample + container (wet):	717.06	Wt of Moist:	70.2
Weight of sample + container (dry):	646.96		
Weight of container (tare wt.) :	283.99	wt. of soil:	362.90

S/N: Oven: 707769 / Scale: 719957 Cal. due date: 1-04 / 10-03

Carol Strong RWMC SOIL MOISTURES INEEL Materials Lab

Project: Soil Sampling For Nuclear Logging - Soil Moisture Verification Date: 9-11-03

Sample ID #: SMV 00101M7 - Lablog 047 HAL-1 7% % Moisture = 8.4%

Weight of sample - container (wet): 935.18

Weight of sample + container (dry): 884.54 Wt. of Moist: 50.64

Weight of container (tare wt) : 284.51 Wt. of soil: 600.03

Sample ID#: SMV 00101M7 - Lablog 048 HAL-1 8.5% % Moisture = 7.9%

Weight of sample + container (wet): 794.74

Weight of sample + container (dry): 757.58 Wt. of Moist: 37.16

Weight of container (tare wt) : 284.39 Wt. of soil: 473.19

Sample ID#: SMV 00201M7 - Lablog 049 HAL-1 11.5% % Moisture = 6.8%

Weight of sample + container (wet): 649.82

Weight of sample + container (dry): 626.55 Wt. of Moist: 23.27

Weight of container (tare wt.) : 282.38 wt. of soil: 344.17

Sample ID#: _____ % Moisture = _____

Weight of sample + container (wet): _____

Weight of sample + container (dry): _____ Wt. of Moist: _____

Weight of container (tare wt.) : _____ wt. of soil: _____

Sample ID#: _____ % Moisture = _____

Weight of sample + container (wet): _____

Weight of sample + container (dry): _____ Wt of Moist: _____

Weight of container (tare wt.) : _____ wt. of soil: _____

Sample ID#: _____ % Moisture = _____

Weight of sample + container (wet): _____

Weight of sample + container (dry): _____ Wt of Moist: _____

Weight of container (tare wt.) : _____ wt. of soil: _____

S/N: OVEN: 707768 SCALE: 719957 Cal. due date: 1-04 / 10-03

ATTACHMENT 3
CHAIN OF CUSTODY

435.20
05/16/2000
Rev. 01

INEEL SAMPLE MANAGEMENT OFFICE
CHAIN OF CUSTODY FORM

19399

See Instructions On Back

Page 1 of 1

[1] Sampler (Printed):	[2] Sampler (Signature):	[3] Project Name: Soil Sampling for Nuclear Logging Soil Moisture Verification
CAROL STRONG	Carol Strong	
[4] Laboratory Shipped To: CFA MATERIALS TESTING LAB - CRAIG	[5] Sampling & Analysis Plan Number: INEEL/EXT-01-01538	[6] TOS/SOW/PSR Number: NA (CORT 03-09)

[7] Sample ID#	[8] Sample Date	[9] Sample Time	[10] Sample Location	[11] Depth FT	[12] Sample Matrix	[13] Analysis Type No(s)	[14] Preservative	[15] Remarks
041 SMV00601M7	9-10-03	14:38 (Z 9-10-03)	UEU-4-HIGH	1.0	SOIL	MOISTURE	NA	PLASTIC BAG
042 SMV00701M7		14:53	UEU-4-HIGH	2.0				
043 SMV00801M7		14:57	UEU-4-HIGH	3.0				
044 SMV00301M7		15:07	UD-1-MED	1.0				
045 SMV00401M7		15:12	UD-1-MED	2.0				
046 SMV00501M7		15:19	UD-1-MED	3.0				
047 SMV00001M7		15:33	HAL-1-LOW	1.0				
048 SMV00101M7		15:38	HAL-1-LOW	2.0				
049 SMV00201M7		15:43	HAL-1-LOW	3.0				

C. STRONG 9/10/03

[16] Comments: Results to be sent to Michele Johnson in TSB with a copy to CAROL STRONG at RWMC, WMF 657.

Cooler Number(s):

[17] Relinquished By (Printed)	[18] Relinquished By (Signature)	[19] Date	[20] Time	[21] Received By (Printed)	[22] Received By (Signature)	[23] Date	[24] Time
CAROL STRONG	Carol Strong	9-10-03	16:25	HC BEAN		9-10-03	16:25

Distribution: Original & Yellow: Accompany Shipment To Laboratory Forward To Sample Management Green: Returned By Project

ATTACHMENT 4
RWMC OPERATIONS RELATED TASK

Approved to work
Rtt 7/16/03

RWMC OPERATIONS RELATED TASK

ORT No.: 03-09

Task	Hazards	PPE	Other Hazards Mitigation	Applicable Training or Awareness	Comments
Hand auger three holes to a depth of 30 inches in Pit 5, Area 2, and Area 10 in the SDA to collect soil samples. This will be done 6 " from existing probes.	Radiation, environmental conditions, i.e. cold, wind, pinch points.	Hard Hat, Steel-toed Boots, Safety Glasses, Leather Gloves.	Pre-job briefing, JSA-047	RWMC Access, Rad Worker I, Hazwoper 40hr, JSA-047, HASP INEL/EXT-01-01538	Samples will be analyzed for soil moisture.

APPROVAL:

Facility Manager: _____ 9/8/03